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**Primary Teachers' Understandings of
the Nature of Science
and the Purposes of Science Education**

by

Stephen Andrew Lunn, B.A., M.Sc.

**Thesis submitted to the Open University in fulfilment of the
requirements for the degree of Doctor of Philosophy**

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Abstract

With the introduction of the National Curriculum in English primary schools in the late 1980s, the status of science changed from discretionary option, taught to the teacher's strengths, to mandated core subject with tightly defined curriculum.

During the first few years, teachers' initial uncertainty gave way to growing feelings of competence and confidence, which local, national and international evidence from the mid-1990s onwards shows were not entirely misplaced. Meanwhile, however, a series of studies consistently showed apparently severe gaps in primary teachers' science knowledge - so what was it that was changing?

Teachers themselves hold the key to understanding how science has been accommodated into primary practice: this research looks at some teachers' views of the nature of science and the purposes of teaching it; the manifestation of such views in planning and teaching; changes in views over time; and the accommodation of science teaching into their professional identities.

Drawing on a 1996 pilot study, the research involves case studies of five teachers - biographical and semi-structured interviews, protocol analysis, and lesson observations, over eighteen months from early 1998; a questionnaire survey of a broader sample; and triangulation between case studies and survey.

Various factors that may underlie a teacher's view of the nature of science are proposed - scientism, naive empiricism, new-age-ism, constructivism, pragmatism, and scepticism. It is suggested that teachers' accommodation of science into their practice can involve its structural and organisational interweaving into the fabric of their professional identities. A tentative hypothetical model is outlined, of the emergence of professional identity from an autopoietic network involving auto-biography; values; dispositions; beliefs; personal theories; self-image; knowledge of and relationships and discourse with children and colleagues; curriculum, subject and pedagogic knowledge; images of teaching and learning; the exercise of agency in practice; and reflexive connections between, and reflection upon, these.

Foreword

My grateful thanks are due to all the teachers who took part in the project, to their colleagues who made their participation possible, and to their pupils, who tolerated the strange person in the corner of their science lessons; to my supervisor Joan Solomon, for all the things a supervisor is supposed to do and much more; to the Open University's Centre for Science Education staff, research students, and head of department Jeff Thomas, for unstinting support and good fellowship; to Donald McIntyre, Geoff Hayward, Laurence Viennot, Albert Paulsen, Andrew Pollard, Keith Postlethwaite, Ghazala Bhatti, Patricia Murphy, and Christine Khwaja, amongst many others, of Cambridge, Oxford, Denis Diderot (Paris 7), Royal Danish, Bristol, Exeter, Reading, the Open and Middlesex universities respectively, for their support and their generous gifts of time for discussion and advice; to the many other educationalists, academics and researchers, on whose 'giant shoulders' I hope my small contribution will stand; to the OU library, research degrees centre, and research training and support staff, especially Karen Vines, the statistics advisor; to the good companions on my Oxford research methods course, and to my fellow OU research students, especially those who took part in the 'Dipsy' group; to Karla, Molly and Billy, who took me for regular walks on the meadow; to my wife Imogen Rigden, chief guinea-pig, sounding board, 'blind duplicate coder' and counsellor, whose patience was long when mine ran short; and to our children, Benjamin, Joseph and Amy, who have also had to put up with quite a lot, and whose hunger for understanding and fairness shows us one of the reasons why education is the most important process in our world.

Stephen Lunn

Wolvercote, Oxford

September 2000

1. Introduction

1.1 The purpose of the research

The implementation of the National Curriculum in England and Wales over the last ten years has seen science move from being an option that was taught in primary schools at the teacher's discretion and according to the teacher's strengths and interests, to its current status as a 'core' subject alongside English and maths, with a highly specified curriculum. The framing of the National Curriculum implies that the learning of the specified items and 'attainment' of the specified 'targets' constitutes the goal of science education at each 'key stage'. It appears that not only is a specific selection of science content being imposed, but also a philosophy of science education which tends to stress the assessable, i.e. content knowledge ahead of process skills, understanding and affective aspects - in a combination which leads to a focus on the science content knowledge of primary teachers. The opinion of many policy-makers and educationalists seems to be that 'generalist' primary teachers cannot do justice to the science element of the curriculum, through lack of subject knowledge, pedagogical knowledge and confidence: they prefer an approach based on specialist subject teachers. Teachers must "possess the subject knowledge which the Statutory Orders require" but the amount of knowledge required "makes it unlikely that the generalist primary teacher will be able to teach all subjects in the depth required" (Alexander et al 1992).

Recent developments have seen the more unrealistic demands of the National Curriculum being ameliorated by reductions in the number of mandated subjects, though the science curriculum is little changed. One school of thought (e.g. Summers 1994) holds that: there is a problem with primary science; the problem arises from a deficit in the teachers' subject knowledge; the way to solve it is to identify the 'substantive content knowledge' (such as the curriculum for initial teacher education, DfEE 1997b, 1998b) and the associated 'pedagogical content knowledge' that the National Curriculum requires, to create (constructivist) teacher-education materials based on these, and to educate primary

teachers pre- and in-service using these materials and a constructivist approach - one which involves identifying and correcting prior misconceptions. As Pomeroy (1993) points out, the proponents of such an approach tend to have been subject to "a deep initiation into the norms of the scientific community", having pursued a science specialisation through their own upper secondary and tertiary education, and on into secondary school science teaching. As a result their views on the nature of science may be deeply engrained and implicit throughout their thinking, but not considered problematic or debatable and not subject to critical appraisal. Though constructivist in intent, the work focuses on conceptual change in isolated curriculum areas and pays no attention to teachers' understanding of the scientific enterprise as a whole, failing to address the need for an integrative view of how systems of scientific knowledge fit together. The idea of a direct causal connection between such 'islands' of science content knowledge and teaching confidence is seen here as an over-simplification associated with this 'knowledge deficit' model of primary science teaching: a model incorporating teachers' professional identities, values, beliefs, images and experiences may be more realistic. The intention is to look into the states, structures and ontogenies of primary teachers' thinking in this area.

In general terms, we need to understand better the educational and social processes going on in schools. One factor in this is what teachers are thinking and doing, why they are thinking and doing it, and how they reflect upon their practice; and one line of attack on this is to find out what the teachers themselves think about what they are asked to teach, and their accommodation of it into their professional lives. We need to know whether there is a problem and if so what its nature is, in the eyes of the practitioners - as a necessary (though not sufficient) pre-condition of rational decisions on future curriculum, the role of subject specialists, and the design of pre- and in-service training programmes; and we need to understand what primary science is, in the eyes of those who teach it, in order to understand the images of science being presented to the children.

This thesis describes some research into primary school teachers' perspectives on science, science teaching, and their science- and education-related life histories. A brief history of primary science education is followed by a review of the relevant literature, drawing on diverse sources, from the philosophical to the professional. A pilot study carried out in 1995-96 is summarised, and the research questions are defined and evaluated. Following a methodological discussion and an account of the research design, the results are presented in detail. Finally the results and their implications are discussed. Appendices are attached containing background information and data supporting the reported results.

In sketching the 'scientific context' of educational research, the ESRC (1999, p3-6) identifies two main perspectives - one whose pre-occupation is the identification of 'what works' through "experimental or quasi-experimental studies designed to establish and communicate a body of safe knowledge" which can be more or less directly implemented; and one whose focus is on contextualised understanding, an 'interpretive' perspective that is "intended to promote wise judgement in emerging situations". The ESRC sees both perspectives as valid potential contributors to "improvement in learning outcomes", the most prominent loci for such *improvement* being the motivation and engagement of pupils; the *intellectual processes* associated with learning; and the learning of professional educators. In relation to the ESRC's analysis, this research can be positioned as: seeking a contextualised understanding, within an interpretive perspective, of primary teachers' accommodation of science teaching into their practice. Its locus is the learning of professional educators, though it also provides insights into their perspectives on the motivation and engagement of pupils, and the intellectual processes associated with their learning, in relation to primary science.

1.2 The recent history of primary school science

Before the introduction of the National Curriculum, what science was taught in primary schools, and how it was taught, was at the discretion of the teacher, school or local authority. The pendulum of opinion swung between a very traditional

emphasis on 'the basics', the 3 Rs, in which science was represented by 'nature study' if at all, and 'progressive', 'child-centred', 'discovery learning' approaches (see Shulman and Keislar (eds), 1966; Entwistle, 1970). In practice, this meant that primary education as a whole and primary science in particular was very varied in content, philosophy and style. Dearden (1968) attempted to put it on a rational footing: his argument in relation to science was two-pronged:

- (i) in spite of the modern pluralism in values, a substantial consensus remains which numbers economic viability high among the desiderata of future society: this points to the teaching of 'basic skills' and mathematics, science and language in primary schools;
- (ii) though the school cannot prejudge the choice of values by which one is to live, it has a role in relation to that choice, for rational choice itself is rich in presuppositions - that one will indeed choose, and not just be told what to believe and do: it presupposes "a well grounded understanding of one's situation in the world", which, he argues, is constituted of mathematical, scientific, historical, aesthetic and ethical elements. (p59-61)

He saw no justification for distinguishing, within a simple experimental, observational and mathematical approach to science, between the different natural and human sciences in which interesting work might be done, expecting that during their primary education children would touch on physics, chemistry, biology, meteorology, geology, astronomy, physical and economic geography, elementary anthropology, aspects of the psychology and physiology of perception; and that they would do some local community studies, within the same observational and mathematical approach. (p84-5)

The work of Dearden and others was built on by policy-makers through the seventies and eighties, though the wide variation in philosophy, purpose and practice in primary science persisted until 1989, when the National Curriculum was introduced and science

became a 'core subject', alongside maths and English, from age 5 to 16 (DES, 1978, 1985, 1988, 1989).

Before the introduction of the National Curriculum there had been no governmental or locally imposed curriculum in primary schools at all. There was a requirement to give religious instruction but this had been 'more honoured in the breach'. Some schools, probably the majority, did teach some science but the content they chose ranged from bee-keeping to electric circuits with little discrimination (Solomon 1989). The new curriculum met with some resistance from teachers, perhaps simply because of the compulsion, the specification of content where there had been none before, which may have seemed like a curtailment of professional liberty, and also confronted the teachers' own knowledge of science.

Early reports (e.g. Wragg et al 1989), following the introduction of the curriculum, suggested a lack of confidence at this time amongst primary teachers, who ranked science amongst the bottom three of the ten subjects that they were required to teach. Each subject was ranked on the basis of how competent they felt in teaching it, which is taken to be an indicator of confidence. Two years later, science had moved up to third place (Bennett et al 1992): a surprising result in the light of papers such as Kruger et al (1990), Mant and Summers (1993), Summers (1994), which showed apparently severe gaps in teachers' scientific content knowledge when judged by objective academic standards.

Teachers' confidence was not entirely misplaced, as national, international, and local evidence shows. Attainment in science in national tests at 11 years old appeared to rise steadily once the assessment regime had settled down (DfEE 1996a, 1996b, 1997a, QCA 1998), notwithstanding doubts about their validity and factual focus (e.g. ATL, 1996; Close et al., 1997). English primary pupils were amongst the best in the world in international comparisons of attainment in science (Harris et al 1997) which sought to balance the content-focus of most national assessment regimes, with a more balanced assessment taking process and problem-solving more into account. Gunnell (1999)

describes a meeting between Heads of Science from Gloucestershire secondary schools, and groups of pupils at the end of KS2. The former were:

- ‘very impressed by the pupils’ knowledge and understanding of science and science investigation’;
- unanimous in believing that the primary schools’ aims of promoting independence and initiative were being accomplished;
- unanimous in believing that children transferring from KS2 to KS3 enjoyed and were enthusiastic about science.
- were not only impressed but surprised and ‘rattled’, and went back to their schools determined to re-assess their expectations and the induction of their Y7 intake.

So teachers were becoming more confident, and children’s attainment was high and improving, especially in relation to factual knowledge; yet teachers’ subject knowledge was consistently found to be poor. This anomaly suggested that the act of teaching had somehow transcended the subject matter and given teachers confidence by another route: this issue is at the heart of this project’s attempts to understand how individual primary teachers have accommodated science teaching into their professional practice, and how various perspectives on science teaching are distributed in the primary teacher population.

2. Literature review

2.1 Introduction

This section explores various perspectives on the nature of science, on science teaching in primary schools, and on teacher thinking and professional identity, looking at:

- the views of the ‘professional’ thinkers about science, i.e. various recent and contemporary philosophers of science, revealing lively debate and a diversity of credible positions so great that the boundary between these and the ‘lay’ views of members of the public becomes hard to define
- the views on the nature of science of the general public, secondary science teachers and pupils, and primary teachers, exhibiting a range of possible attitudes which can vary with context for any individual; a frequent focus on the factual as opposed to the theoretical; lack of coherence, consistency and consideredness; and a suggestion that primary teachers may be more in tune with contemporary philosophers of science than either secondary science teachers or working scientists
- educationalists’ views on science education in primary schools, suggesting that, though much has been written about primary science teaching, there has been little systematic effort devoted to understanding the positions of the teachers themselves, to hearing their voices
- philosophical considerations and research findings on teachers’ thinking, knowledge, confidence and professional identity, revealing a subtle network of influences and interdependencies, and movements towards a theory of professional identity.

2.2 Philosophies of science

Thinking about the philosophy and nature of science has been more vigorous and diverse over the last thirty or forty years than perhaps ever before, as the confident and unified positivism and reductionism of the past has been attacked from within and without

science, within and without philosophy, and as a narrow focus on philosophical issues, with a normative flavour, has broadened to include sociological and psychological perspectives, and the study of science as is, rather than as various arguments say it should be. The philosophical and ideological battlegrounds of the academic world provide a pluralist milieu where science proceeds despite the lack of common ground, and to a large extent, perhaps, in wilful ignorance of it. The issues that divide the protagonists are epistemological, methodological, ontological, demarcatory, developmental, and paradigmatic .. the purpose here is not to argue for or against particular positions, but to illustrate their diversity and to maintain that, despite their diversity, all are credible positions held by reasonable people. It is against the background of the complexities and subtleties of these debates amongst those studying science and reflective scientists, that any reported lacks of consistency or coherence in the views of the nature of science held by the public, teachers and pupils, should be seen .. and seen as hardly surprising.

Cunningham and Fitzgerald (1996) identify seven main issues in epistemology, each being a continuum along which important historical and current epistemologies differ, and which together comprise a multi-variate space in which the major theories of knowledge can be placed, falling into five 'clusters' of epistemology. The issues are: whether we can have knowledge of a single reality that is independent of the knower; whether there is such a thing as truth; what primary test proposed knowledge must pass in order to be 'true' in some sense (correspondence, coherence or pragmatism); whether knowledge is primarily universal or particular; where knowledge is located relative to the knower (various forms of dualism, monism, pluralism); the relative contributions of sense data and mental activity to knowing; and the degree to which knowledge is discovered as opposed to created. The five clusters or epistemological positions are:

- positivism/radical empiricism
- hypothetico-deductivism/formalism
- realism/essentialism

- structuralism/contextualism
- post-structuralism/post-modernism.

So for example the realist/essentialist position differs from all the others in holding that we can have knowledge of a single reality that is independent of the knower, and that correspondence with this reality is the primary test of truth; positivism and postmodernism deny that there is such a thing as truth and the universality of knowledge; structuralism/contextualism and post-structuralism/post-modernism argue that knowledge is created rather than discovered.

These are, of course, gross simplifications of the positions of individual protagonists: for example a modern realist position is argued by Bhaskar, whose general philosophy of science, 'transcendental realism', and whose special philosophy of the human sciences, 'critical naturalism', are elided into 'critical realism', a short précis of which might be follows:

- Realism in perception stands against idealism, and holds that "material objects exist independently of our perceiving them .. the conceptual and the empirical do not jointly exhaust the real. *Transcendental realism insists that the empirical is only a subset of the actual, which is itself a subset of the real.*"
- Realism in the theory of universals is opposed to nominalism, conceptualism and resemblance theory, standing for the existence of universals independently of, or as the properties of, material things. "Transcendental realism holds that some (typically scientifically significant) classes, or ways of classifying objects, constitute natural kinds, but most do not .. "
- In the philosophy of science, realism asserts that "the objects of scientific knowledge (such as causal laws) exist relatively or absolutely independently of their knowledge... Transcendental realism not only affirms this, but articulates the general character that the world must have (for instance it must be structured and differentiated, and characterised by emergence and change) if it is to be a possible

object of knowledge for us. Critical realism embraces a coherent account of the nature of nature, society, science, human agency and philosophy (including itself). Its intent is to underlabour for science, conceived as a necessary but insufficient agency of human emancipation." (quotes are from Bhaskar 1989, p190-191).

Popper's (1968) major contribution to the philosophy of science was his insistence on falsifiability as a criterion of 'scientificness' of a knowledge claim: he also argued for the possibility of knowledge without a knowing subject, in his 'third world' of objective knowledge (the first two being the physical and the mental worlds respectively) (Popper, 1972). This is very distant from the view of knowledge underlying the present work, which is focused specifically on the knower: Kuhn's 'contextualist' view is similarly located in human knowing. Kuhn's view of science distinguishes 'normal' - gradual and progressive development within a broadly accepted world view or paradigm - and 'revolutionary' phases, during which the world view is fundamentally redefined in a way that renders earlier views obsolete, and makes the new view 'incommensurable' not only with older views but also with older problems and questions. Scientific knowledge is produced within a paradigmatic context, by consensus in (subsets of) the scientific community (Kuhn 1970). Popper (1970) counters that differences of 'world view' or paradigm do not make for 'incommensurability' as Kuhn argued: "a critical discussion and a comparison of various frameworks is always possible. It is just dogma .. that different frameworks are like mutually untranslatable languages" (p56), while Laudan (1984) argues for what appears to be a gradualist position which is claimed to supersede Kuhn's 'paradigm shift' approach. He argues that one or more of the following are undergoing change at any one time:

- the intentions of inquiry
- the theories and models being used to guide it
- the methodological rules under which data are collected and evaluated

and that apparent paradigm shifts in a historical perspective are actually an accumulation of many such micro-shifts.

Lakatos argues that scientists use theories as tools for organising and interpreting their knowledge; for solving the problems they consider important; and to help see new possibilities and new problems - working within 'research programmes' with common methodological foundations (Lakatos 1970). In contrast Feyerabend (1975, 1981) argues against any homogeneous scientific method, and claims that scientific theories can only be genuinely tested when an alternative theory becomes available and allows an alternative view of phenomena to be taken. His review of the history of science showed that no single substantive methodology could be discerned in it; he went on to argue that this showed the lack of a rational basis for science, and hence that there was no justification for privileging scientific beliefs over those of, say, shamanism.

The postmodern position, that all knowledge is socially constructed and contextual, and that there are no forms of representation, meaning or rationality that can claim universal status, is held by Collins and Pinch (1982), amongst others. They claim to have shown through empirical study that

philosophies of science that depend heavily upon the invocation of experimental evidence to decide between major differences in theoretical perspective are not tenable (p184).

Latour and Woolgar (1986) describe science as

a body of practices widely regarded by outsiders as well organised, logical and coherent, [which] in fact consists of a disordered array of observations with which scientists struggle to produce order (p36)

and argue that science is just another form of discourse, one exhibiting the 'truth effect', a literary effect arising from textual characteristics such as the tense of verbs and modalities.

Abrams and Wandersee's (1995) research into the growth of knowledge in biology took a sociological perspective on research practice in the life sciences. They concluded that here at least, the major dynamics for change in science are society's broad aims for science (a subset of which are adopted by scientists), and access to funding; and that

novel methods and theories play a lesser role. Campbell (1974) proposes an evolutionary model of ‘unjustified variation and selective retention’ in scientific discovery; Kitcher (1993) argues for an understanding of science based on a model of practice informed by a psychological theory of cognition, giving a central role to imagery, and developing an elaborated understanding of what constitutes a scientific paradigm; Toumey (1996) explores the ‘conjuring’ of science in furtherance of various political and commercial agendas; Ziman (1984, 2000), with perhaps the most considered and catholic approach of all, embeds science in a network of historical, philosophical, psychological, sociological, cultural, technological, economic, and political ideas and processes; and an interesting approach is being pursued by Gell-Mann (1994) and others at the Santa Fe Institute, which locates science in a broad class of processes known as ‘complex adaptive systems’, around which a body of mathematical and theoretical understanding is developing, offering the possibility of an approach to the study of science which is more theory-based than the sociological empiricism of Collins and Pinch, while being more empirical and phenomenological than philosophical and normative.

As promised, we have found evidence of lively debate, and a diversity of positions. Sometimes these positions are in direct opposition: often they are what might be termed orthogonal, addressing different issues. Evidence of their credibility could be looked for in the time and space given to them by the academic community(-ies), or internally, in their own persuasiveness: either way it is evident that there are a wide range of credible positions, and that a certain amount of context-dependency and pluralism is to be expected: indeed we might look with suspicion on any claim to have found a single, ‘correct’ account. Hence if we find similar context dependency and pluralism in teachers’ views of the nature of science, we should not be surprised.

2.3 Research into understandings of the nature of science

2.3.1 Public understandings of the nature of science

Research on the public understanding of science has shown that the public’s views on the nature of science are neither constant nor coherent, varying from one context to

another (Durant et al 1989) and that even people at medical risk are more likely to seek factual information than conceptual explanation (Lambert and Rose 1990). In general the focus is on factual knowledge, with little interest in anything theoretical (Michael 1992). Solomon (1997a, 1997b) follows Miller et al (1980) in identifying three publics for the 'reception' of science: rejectors; users of 'facts' but rejectors of deep explanations; and the interested and curious, akin to Miller's 'attentive public'; but finds this transmission model, where scientists transmit and the public receive, unsatisfactory, and suggests that there is no evidence that these three reactions define three permanently distinct populations - anyone can act in any of the three ways, depending on context; and in any one context, the majority are likely to fall in the middle group, devaluing science as 'just facts', and with a self-image containing the idea that 'ordinary people like me don't understand that sort of thing'. She sees two incentives for being open to science - social solidarity with scientists as a community, and individual curiosity: giving rise to social and personal reasons for learning, respectively, and suggests that the attitude taken depends on 'locus of control' and 'instructional density', citing Giddens' (1990) view that the public's trust depends on the reliability and probity of a person or institution, rather than their arguments or an understanding of issues. She suggests that pupils at school fall into three groups in similar ways, the interested and attentive group comprising those whose home cultures and peer group preferences 'are congruent with the culture of science'.

If these 'lay' responses and perspectives were reflected in the views of primary teachers and in their teaching of science in primary schools, we might expect some variation from topic to topic, for any one teacher; and three broad ways of relating to science, which, if translated into classroom practice, could, hypothetically, produce three main types of approach to science teaching:

- 'rejectors' - perhaps anti-intellectual, subscribers to 'common sense'; or followers of a modish hyper-relativism - whose engagement with and exploration of science may be minimal and whose presentation of process may be naïve;

- in the middle ground, emphasis on acquisition of content knowledge at the expense of process skills, deep understanding, and affective aspects; or on the latter at the expense of the former; or on technological aspects at the expense of understanding
- enthusiastic engagement with content, perhaps through process; promoting understanding through theoretical models; and prioritising affective aspects like curiosity, interest and a sense of wonder.

2.3.2 Secondary science teachers' understandings of the nature of science

Gordon (1984) argued that science teachers perpetuated a 'bucket' image of science, transmitting it to their pupils as a 'hidden curriculum' which was accepted uncritically. He saw schools as central to the transmission of this image, which was an important factor in shaping an endemic world view in which science functions as a central metaphor, carrying with it ideas of change and innovation as progress, and a preference for reductionism over holism. However Lederman and Zeidler (1987) found no simple relationship between biology teachers' conceptions of the nature of science, as measured on Rubba's (1976) 'Nature of Scientific Knowledge Scale' (which tests the degree to which scientific knowledge is held to be amoral, creative, developmental, parsimonious, testable, and unified), and their general classroom behaviour, as described by quantitative comparisons based on categories derived from 'intensive qualitative observations'. These categories, though, were rather crude and general (e.g. Amoral: scientific knowledge is/is not presented as amoral; Receptive: teacher is/is not receptive to student initiated questions) and it is not clear how subtle variations in teachers' perceptions of the nature of science might be expected to be reflected in variations in such categories. They claim that there is a perennial assumption that teachers' conceptions influence their behaviour and that improved student conceptions necessarily follow improved teacher conceptions, and that their investigation does not support this assumption; and they imply that, therefore, the assumption is false. However this does not prevent them concluding that "a more balanced treatment of the history/philosophy of

science and specifically targeted teaching behaviours/skills is needed in pre-service and in-service science-teacher education if we are to successfully promote more adequate conceptions of the nature of science among our science students". (p372)

Brickhouse's (1991) intensive study of three science teachers of varied backgrounds and experience agreed with Gordon that the teachers' understandings of the nature of science shaped an implicit curriculum on the nature of scientific knowledge. The research examined links between teachers' views of the growth of scientific knowledge and the methods they used to help students construct a knowledge of science. Three science teachers' conceptions of the nature of science, their roles as teachers, and their students' roles as learners were investigated through interviews, classroom observation, documentary evidence, and respondent validation of case study reports. Brickhouse concluded that teachers' views of the nature of science are expressed in their classroom behaviour; their views of how scientists construct knowledge are consistent with their beliefs about how students should learn science; content knowledge is an important basis for effective classroom instruction; and that it is therefore important that science teachers understand three aspects of the "current conception" of science - its socially constructed nature; the relationship between observation and theory; and the nature of scientific progress (p59). She suggests that future research should look at where and how teachers' understandings of the nature of science originate; whether they are or could be influenced by teacher education; and how their beliefs are translated into "pedagogical content knowledge and through it into practices that affect students' scientific understanding and their activity in science". (p61)

Helms (1998) supports Brickhouse's main findings. She has explored the relationship between subject and identity, and thus, for science teachers, between the nature of science and the nature of self, thus offering an insight into how the teacher's self mediates between subject and classroom practice. Lederman (1999) on the other hand is still finding that "teachers' conceptions of science do not necessarily influence classroom practice. Of critical importance were teachers' level of experience, intentions, and perceptions of students". (p916)

Unsurprisingly, if Helms' view of the mechanism underlying the influence on classroom practice of a teacher's views on the nature of science is anywhere near right, Mellado (1997) found that there was no significant relationship between classroom practice and their views of the nature of science amongst *pre-service* teachers, who have not had the opportunity to explore their understandings of the nature of science in the melting pot of practice, and Simmons et al (1999) found a similar pattern with beginning teachers.

More recently Brickhouse has shown that, though student teachers' ideas about the nature of science change over a course of instruction, they still end up at odds with the prevalent ideas in science education literature and standards (Brickhouse et al. 2000); however it is interesting to note that most practising scientists also disagree with such ideas (Harding and Hare 2000).

Koulaidis (1987), and Koulaidis and Ogborn (1989, 1995), argue against assuming that "teachers have one or other completely consistent view of the nature of science .. they hold eclectic or mixed views, adhering to a diversity of elements taken from different philosophical positions .. the role of philosophical analyses of science .. is not to provide ready-made total positions for teachers to be slotted into, but rather to construct a collection of elements, i.e. positions on different philosophical themes, which can be used to analyse and represent teachers' thinking. (Koulaidis and Ogborn 1995, p280). Their earlier work detected a movement away from inductivism, which they now find depends on the theme addressed - methodology, criteria of demarcation, patterns of scientific change, status of scientific knowledge. They call for further work on the interaction between teachers' views on these themes and their views on philosophical issues of relevance to science teaching such as explanation, causality, and modelling; and the identification of factors which might influence teachers' views. They suggest that the ideas of science used by teachers may vary depending on the context; that different groups of teachers, and the moral dimension of teachers' views, should be investigated; and that the views of primary teachers are of special interest. Results obtained by Koulaidis (1987) indicate that teachers tend to consider theoretical entities as real; and that there is a correlation between teachers' ontological and curricular views: teachers

who hold to the reality of theoretical entities tend to prefer the teaching of specialised subjects (as opposed to integrated science), and to make rigid distinctions between process and content (Koulaidis and Ogborn 1995, p280-1).

Lakin and Wellington (1994) used repertory grid techniques to elicit views of the nature of science from eleven experienced science teachers. Individual teachers had quite different views of science, especially the degree to which it involves subjective observations, emotions, intuition, truth, chance, imaginative thought, hierarchical knowledge, morality, spiritual beliefs, and is determined by culture. Though willing to talk, teachers were not giving well thought out, considered views, but were 'thinking on their feet' and amending their ideas as they talked. Teachers were found to lack knowledge about the nature and history of science, and to recognise that their knowledge was patchy: "non-verbal signals reflected an insecurity when the issues were probed in depth. Teachers were looking for confirmation that their interpretations were acceptable and were the 'correct ones'.. little reflection on the nature of science had been made prior to the teachers' involvement on this project .. teachers were unclear about the 'scientific method' although it forms the cornerstone of the investigation of science component of the curriculum .. It would not be prudent to suggest, on the basis of this study, that teachers are 'naive inductivists' or to apply any other label.. The picture is far more complex .. The only common features appear to be a lack of reflection about the nature of science and a feeling of insecurity tinged with traces of elitism". (p186)

Thus recent research into secondary science teachers' understanding of the nature of science shows that most teachers do not hold what philosophers of science would see as complete and consistent views of the nature of science, but rather draw on diverse elements from different philosophical and 'common-sense' positions; and that their views are not well formulated and have probably been only rarely articulated. There is also contested though fairly convincing evidence that their views of the nature of science can and often do influence their classroom practice, particularly amongst more experienced teachers.

It is perhaps also worth noting that all of this research into teachers' views of the nature of science seems to start out with some sort of category system developed from *a priori* sources such as the history and philosophy of science, and attempts to match teachers' views to them - rather than starting with teachers' unprompted accounts of their views, which could well reveal quite different category systems, and quite different relationships between views and practice. For example, building on a model developed by Koulaidis and Ogborn (1989), Nott and Wellington (1993, 1998) describe a model of "paired philosophical constructs", that are "supposed to behave as opposites", thus providing a series of continua or dimensions in each of which they can locate a particular teacher's views. Their continua are:

- relativism-positivism
- inductivism-deductivism
- contextual-decontextual
- process-content
- instrumentalism-realism.

There are two main problems with this approach:

1. the notion that one person will occupy one position on any particular dimension is very dubious - for example, it seems perfectly reasonable to be an instrumentalist with respect to quarks, at the same time as being a realist with respect to viruses, and somewhere in-between on neutrinos
2. the notion that it bears any relation to the way that teachers actually conceptualise science is at best a hypothesis: but if you define such a space, and ask just enough questions to position someone in it, but not so many that their position becomes several diffuse clouds of possibilities, you could create the illusion that it really was a satisfactory way to map teachers' conceptualisations.

2.3.3 Secondary pupils' understandings of the nature of science

Dillon (1994) bemoans the emphasis on quantitative models in science, pointing out that, though expert practitioners in science and engineering frequently reason about the world in non-quantitative ways, this aspect of the 'normal' culture of science and technology is largely ignored in education, "distorting students' understanding about what constitutes authentic everyday activity amongst subject experts" (p55) in a way that accentuates its more abstract and inaccessible aspects. Larochelle and Desautels (1991) interviewed 25 secondary school students, finding 'naively realistic and empiricist postulates underlying their representation of scientific knowledge and its production' (p373).

The constructivist perspective figures prominently in some research, for example Carey et al (1990) report on 12-year-olds' epistemological views before and after a teaching unit designed to introduce the constructivist view of science. They were able to 'move' students from their initial epistemological stance (scientific knowledge is a passively acquired, faithful copy of the world; scientific inquiry is limited to observing, rather than constructing explanations about, nature); but query the validity of such 'gains' since the post-treatment interviews required only that students repeat points made explicitly several times during the teaching. They identify the need for further research on whether students' understandings of the nature of science have any impact on their learning of science content, 'especially in those cases where conceptual change is required'. (p526)

Driver's influential monograph, *'The pupil as scientist?'* (1983), a foundation stone of the constructivist movement in school science, does not report any research on teachers' or students' views of the nature of science, but suggests that educators have invoked theoretical 'support' only to give credibility to common sense inductivist views of the nature of science and of children's learning. However, in *Young people's images of science* (Driver et al 1996), a substantial investigation of 9-, 12- and 16-year-olds' views is presented. Three features are found to characterise scientific endeavours: the possibility of empirical investigation, the domain being in the physical or biological as opposed to social area, and the institutional setting of the work. Views of the nature of

scientific knowledge ranged from the simple - “a picture of events in the world with little distinction being made between evidence and explanations” - to the sophisticated - “a theoretical model of events .. which can be evaluated in the light of evidence”. (p111)

This range of views is elaborated into a general framework characterising the dimensions of students’ epistemological understanding as consisting of three forms of reasoning: phenomenon-, relation- and model-based, each with distinctive forms of enquiry, kinds of explanation, and relationships between explanation and description. The prevalent form in 9-year-olds was phenomenon-based; and in the other groups, relation-based. Model-based reasoning occurred and its occurrence increased with age, but only in ‘one or two’ students was it manifest in “an awareness of the conjectural nature of theories and their provisional status” (p117). Students’ tendency to see explanation as emerging in an inductive way from data, rather than as conjectural and hence underdetermined by data, may limit their ability to make sense of scientific controversies and disputes.

Solomon has worked extensively in this area. In *‘Is Physics Easy?’* (Solomon 1983) she reports research in which pupils were asked whether they knew the everyday meanings of words like ‘stability’, ‘conservation’, ‘energy’; the results were compared with their performance in a written test. The less successful often denied any difference between physics definitions and everyday meanings .. despite their low scores, they asserted that ‘physics is just common sense’, or ‘... general knowledge’, or ‘physics is easy’.

Cassels and Johnstone (1985), also looking at language use in science, find that in many cases pupils take the opposite meaning to that intended, e.g. negligible = ‘a lot’; random = ‘well ordered’; and suggest that loose language must give rise to loose reasoning and strange conclusions.

Children’s views on social aspects of science vary with gender and academic ability (Solomon 1985): two possible explanations are proposed:

1. science teachers’ implicit message that the reductive scientific approach is the only one of value: such naive positivism would indicate a need for in-service training in the philosophy of science

2. in line with Schutz' distinction between life-world knowledge and the 'over-arching universe of symbolic knowledge' that constitutes science, school physics could appear to be an 'invitation to a new way of thinking' that only the more able can recognise and take on board (see Schutz and Luckman, 1973).

Solomon argues that "discussion of social issues within science lessons is important, not only because it nurtures citizenship, but precisely because it inhabits that sphere which is perhaps the final goal of true education, where the cognitive is married with the evaluative". (p368)

Solomon et al (1994) look at how pupils' views of the nature of science change when learning materials are 'historically situated'. The study involved five classes of 11-14 year-olds, and used pre-and post-tests, exploratory ethnographic interviews, classroom action research and observation, and class tests, and the results gave hints of a theory of learning and epistemology with connectionist and episodic elements:

The apparently 'successful' changes in the pupils' ideas ... do not show that other more simplistic images have completely disappeared. We would argue only that the stories of the actual activities of scientists are memorable enough to create a library of epistemological ideas in the minds of young pupils. Since we had already rejected the notion that epistemology is the kind of disembodied knowledge which could be abstractly encoded in the memory this was a valuable conclusion to our research (p372).

Solomon (1995) argues that higher levels of understanding are accessible to many pupils, including an appreciation that science sets out to explain natural phenomena by constructing theories, which are mental models, metaphorical redescrptions or analogies of known applicability and limitations, from which predictions can be made which can be tested by experiment and observation; and that experimental results do not have a simple relationship with theory, but require interpretation and are capable of multiple interpretations.

Most recently Solomon et al (1996) report a questionnaire survey of c.800 year 10 pupils, with additional results from 120 year 8 and sixth formers, which explored their

ideas about what 'scientists' do, ideas about theories and how they change, and impressions of how theory and experiment interact in their school science. The results confirmed the powerful effect of the individual classroom teacher, and some interesting findings involving the sub-sample of pupils who have understood the explanatory nature of the science, and the much smaller sub-sample who are beginning to understand the role of imagination and modelling in scientific theory. Girls slightly outnumbered boys in the first group, the 'explainers'. The 'imagers', who comprised about 17% of the year 10 pupils, were even more interested in what goes on in the mind - imagining, expecting, explaining. Overall the study found a progression in pupils' views of science, most of which was attributable to teaching rather than maturation, and depended on the way the teacher linked practical work with theory. The subtleties of the relationships between theory, prediction and experiment, in particular the mental manipulation of theoretical models required to generate hypotheses, the uncertain nature of evidence, and the scope for a variety of interpretations, was a step that few pupils seemed to make, even at sixth form level. Solomon found that few teachers seemed to encourage "the use of models, and reflection on how imagination affects the interpretation of experimental results... We are convinced that it needs special strategies to move pupils on from a worthy but limited empiricism towards the more exciting realms of scientific speculation." (p19)

Thus, research into secondary pupils' understanding of the nature of science shows similar features to that relating to the public at large and to their teachers - a lack of interest in the coherence of the scientific world-view, a widespread 'factual' orientation, and a slowly growing focus on explanations for phenomena.

2.3.4 Primary teachers' understandings of the nature of science

de Boo (1989) looked into the science education background of primary teachers. She reports a survey carried out in Haringey, whose objective was to provide a basis for the development of science-related in-service training for primary teachers that "makes science interesting to them as individuals, relevant to the children they teach and appropriate to their own science background" (p252). Findings from a sample of over

100 teachers were that 74% had studied one or more sciences to O level/GCSE, but most had dropped physics and chemistry at the end of the third year of secondary school; 15% had studied one science (in nearly all cases biology) at A level; 62% had taken a science module during teacher training (almost all of whom had qualified within the last 10 years); and in all cases between a third and a half of those taking any science course were dissatisfied with it (heavy, narrow, exam-oriented, knowledge-oriented, little guidance on how to teach, low status compared with numeracy and literacy), though there were more positive responses to science-related inset. Comparing these results with those of a follow-up study conducted in 1996 (de Boo, 1997), she found that on average, the later cohort had:

1. spent more years studying science
2. studied more sciences (two subjects, or general science, rather than mostly biology in the earlier survey)
3. enjoyed science much more.

Holroyd and Harlen (1995) report an investigation of 550 Scottish primary teachers using survey, interview and teacher-maintained diary notes. The teachers were more confident in teaching maths and English than science; in biological than physical sciences; and of developing process skills than teaching content; males were more confident than females; the recently qualified more confident than the longer qualified; those with some science qualification more confident than others; and many were not confident of their own understanding of what they were to teach.

Tymms and Gallacher (1995) report on variation in pupil attainment in science in relation to variables such as teacher's and pupil's cognitive styles, teachers' formal scientific knowledge, and teachers' pedagogical knowledge (using recent science INSET attendance as an indicator), finding that:

- primary teachers were .. considerably less confident about teaching science than about teaching reading or mathematics and this lack of confidence was significantly related to the 'value added' scores of their classes (p155)

- formal scientific knowledge was unrelated to pupil outcomes .. but .. pedagogical knowledge was positively related to these outcomes (p160).

Wragg et al (1989) report a national survey which saw science ranked amongst the bottom three subjects in terms of primary teachers' perceived competence, and identified in-service training in assessment and testing, technology and science as being their main priorities. However, primary science appears to have benefited from the introduction of the National Curriculum in England and Wales: two years later (Bennett et al, 1992), science had moved from eighth to third place in primary teachers' ranking of subjects by their perceived competence to teach them.

Since the introduction of primary science into the curriculum there has been much research in the UK into primary teachers' misconceptions which indicates a lack of confidence in their own understanding of science, and is mirrored by work in the US. This work tends to see the typical general primary teacher as having a deficit in scientific subject knowledge and in 'pedagogical content knowledge' (defined by Shulman (1986) as an awareness of pupils' preconceptions and a repertoire of appropriate examples, analogies and metaphors to help them to understanding). There is generally an explicit 'constructivist' perspective in this school of thought, with emphasis on the teacher's role as facilitating the pupil's construction of 'scientifically valid' understandings by changing the child's defective preconceptions. Examples of the 'deficit' view include:

- It is widely acknowledged that primary teachers' lack of knowledge and understanding of science is a major impediment to good science teaching in primary schools (Summers, 1994).
- Primary grade teachers are well aware of their weak background in the sciences (Smith and Neale, 1989).
- Many of the mental models of the universe held by the interviewees [primary school teachers] were not in accord with the scientific model (Mant and Summers, 1993).

Mant and Summers observe that teachers are in a similar position to well-educated members of the public, hence similar results might be obtained with non-teachers: the authors, both physics graduates, admit that during the research they became aware of substantial inadequacies in their own understanding of the reasons for observed phenomena.

The educational establishment in England shares the 'knowledge deficit' viewpoint:

Subject knowledge is a critical factor at every point in the teaching process: in planning, assessing and diagnosing, task setting, questioning, explaining and giving feedback. The key question .. is whether the class teacher system makes impossible demands on the subject knowledge of the generalist primary teacher. We believe it does. (Alexander, Rose and Woodhead, 1992).

The authors, at the time a Professor of Primary Education, the Chief Inspector of HMI, and the Chief Executive of the then National Curriculum Council, having been instrumental in creating the impossible situation they describe, seemed intent on creating a discourse of knowledge transmission and assessed attainment of specified targets, in a combination which inexorably led to the 'deficit' view of primary teacher knowledge; and thereby transforming child-centred primary practice into the subject-centred practice of secondary schools.

In North America, in Ebenezer and Hay's (1995) study in Manitoba, a teacher educator, 138 pre-service elementary teachers and their 'co-operating teachers' collaborated in an action research project where a constructivist approach was employed by the teacher educator, to the science element of elementary teacher education, and by the pre-service teachers, to their teaching practice science lessons. The results of the project are couched in terms of issues identified and 'integrative imperatives' for a constructivist 'transformation of pedagogical content knowledge'. Issues included the relationships between children's ideas, curriculum objectives and lesson planning; varying levels of comfort with content knowledge; and the desirability of introducing conceptual conflict. Two integrative imperatives were that

the pre-service teacher and the teacher educator not only 'talk the talk' but also 'walk the talk' and 'walk the walk' together, and that the pre-service teacher personally walks with the children (p104).

Cheung and Toh (1990) explored how beginning elementary teachers in Singapore conceive the scope and nature of science, and science teaching and learning, finding their views piecemeal, lacking coherence and consideration, and at variance with the philosophical positions of Popper, Kuhn, Lakatos, and Feyerabend. They conclude, without explicitly connecting their conclusions with their evidence, that didacticism and a 'performance orientation' constitute significant obstacles to a constructivist pedagogy.

Gustafson and Rowell (1995) investigated elementary pre-service teachers' conceptions of learning, teaching, and the nature of science using questionnaires and semi-structured interviews before and after 13-week elementary science education courses, finding that many hold naive realist or inductivist views, and that there was little change in teachers' ideas from pre- to post-course, despite the constructivist philosophy of the course designers. They conclude that

integrating new ideas into conceptual frameworks seems to demand much more than the relatively brief encounter with a constructivist approach to learning science offered in these courses (p603).

Murcia and Schibeci (1999) found similar results in a questionnaire study of thirty-eight 'mature' and thirty-five 'straight from school' pre-service primary teachers. There were no significant differences between ages.

Pomeroy (1993) reports on differences in scientists' and primary and secondary teachers' views of the nature of science, scientific method, and related aspects of science education, relationships between beliefs about science and science education, and implications for preparing science teachers. She distinguishes 'traditional' and 'non-traditional' views of science, contrasting the

Baconian, logico-empiricist belief that the only way of gaining scientific knowledge was through the application of inductive methods based upon observation and controlled experimentation [with] alternative ideas suggested by Popper, Polanyi,

Keller, Gould and Kuhn .. [non-traditionalists recognise and celebrate] the richness and variety of experiences that constitute valid scientific discovery .. [and] recognise dream, intuition, play, and great inexplicable leaps as potentially part of scientific method. They agree that the ideal of objectivity .. is not only unrealistic but also unlikely to produce meaningful science. (p262)

Surveying a non-random self-selected sample of 180 scientists and teachers in Alaska, she reports that working scientists hold more traditionalist views than either type of teacher; and that secondary teachers hold more traditionalist views than elementary teachers. Pomeroy points out that the more non-traditional views were held by those who had taken fewest science courses, and had least experience of scientific research. While admitting that the effects may be due to sample bias, she offers three possible explanations: that elementary teachers' non-traditional views arise from:

1. their views of how children learn, due to a growing awareness of and commitment to constructivism
2. reflection on their own construction of teaching knowledge
3. participation in in-service workshops emphasising a constructivist approach to science (the study did not elicit whether they had in fact had such training).

The prevalence of traditional views amongst both scientists and secondary science teachers is attributed to their long 'indoctrination' emphasising content and minimising philosophy of science and reflection on process, exacerbated by content-driven textbooks.

Wolfe (1983) discusses the ideas about science communicated to their pupils by elementary school teachers in a study based on systematic observation of science lessons, using an analytical scheme derived from the work of Norwood Russell Hanson who, according to Wolfe, distinguishes two extreme views of science, sensationalism and formalism, and a balanced or '*via media*' (middle way) view. Wolfe adapted Hanson's work to the context of elementary school teaching and developed a set of observation clues which revealed that '*via media*' views are developed during 'ordinary'

science lessons, and that ideas about science are communicated to pupils through the activities of observation, explanation, and experimentation.

Solomon and Palacio (1988) report an interview study of sixteen primary teachers: all were teaching some science, and were able to talk fluently about why they taught it and what its rationale should be. Memories of their own schooling showed biology in a more favourable light than the physical sciences; and an unexpected level of bitterness of memories of failure was found. They supported the goals of development of process skills, of relating school science to everyday experiences, and, more tentatively, of helping pupils gain progressively deeper conceptual understanding; but rejected the ideas that primary science was a preparation for secondary science, that grasping certain fundamental facts was essential to progress, that science should link to and reinforce maths and language work, and that primary science should be modelled on secondary science. Active learning was stressed, as against acquiring knowledge of facts and theories from books and demonstrations. Input from pupils' homes was not positively received; science INSET was welcomed and inspired a range of inventive activities; and the notion of science as a set of processes or a mode of enquiry had freed them from the chains of 'factual' science in their own schooling. The authors ask what will happen to 'this new culture of primary science once the factual content of the National Curriculum comes into force? Already there is a call for more training of primary teachers. Unless such science INSET courses are handled with greatest care, they could set the clock back by a hundred years.'

Akerson et al (2000) assessed the influence of a reflective explicit activity-based approach on elementary pre-service teachers' conceptions of the nature of science. They used an open-ended questionnaire to assess students' positions on the nature of science before and after the course, and found that students had "made substantial gains in their views of some of the target NOS aspects. Less substantial gains were evident in the case of subjective, and social and cultural NOS." (p295)

Overall the research on primary teachers' views on the nature of science seems to be fragmentary. As with the research into secondary science teachers' views, much of it has been based on *a priori* category systems to which teachers' views have been matched, rather than starting with the distinctions teachers themselves make. Much of it has been done with pre-service or beginning teachers: where more experienced teachers have taken part, it is suggested that more developed views have been found, which may have been forged in practical experience of teaching science. Clearly this kind of professional engagement with science distinguishes the primary teacher's experience from that of most members of the public; and equally clearly it is a different kind of professional engagement from that experienced by secondary science specialists. Primary teachers in general may have most in common with those members of the interested and intelligent lay public who have reason to look beyond a factual focus, perhaps into the kinds of theoretical controversy and social process surrounding issues like genetic engineering and global warming, and who perforce reflect on the nature of science as it is manifest in social and political contexts. This blurring of the boundaries between philosophers of science and the rest - including the interested lay public, and people teaching science who are not science specialists - reflects and is perhaps legitimated by the confrontation between Lakatos and Feyerabend mentioned above: certainly it leads us to expect a plurality of positions, from scientism to relativism, empiricism to constructivism, pragmatism to realism, amongst both primary teachers and the lay public.

2.4 Educationalists' views on science in primary schools

Dearden's (1968) insistence on interesting, wide-ranging work within a simple experimental, observational and mathematical approach, not distinguishing between the different natural and human sciences, and his distinction between 'learning that' (scientific knowledge), 'learning how to' (laboratory and research skills), and 'learning to' (a disposition to be scientific when appropriate), was typical of the kind of rationalist approach to the primary science curriculum that persisted until the rise of personal constructivism, on the one hand, and formalisation of the National Curriculum on the

other, in the mid- to late 1980s. Osborne and Simon (1996) recount how the SPACE project (Osborne et al 1990) was influential in the formulation of early versions of the National Curriculum, and was also used during the drafting of the 1995 version. They argue that the curriculum's emphasis on the ontological (what we know) at the expense of the epistemological (how we know), leads to unrealistic demands and expectations of teachers, who need to understand not only that something is so but also the strengths and weaknesses of the evidence as to why it is so. This requires knowledge of the nature, history and philosophy of science more than strictly content knowledge. They follow Milner (1986) and Millar (1996) in arguing that the main aims of primary science are economic, utilitarian, cultural, and literacy and skill development, and claim to demonstrate that "for teachers lacking adequate subject knowledge, the nature of the teaching and learning experience they offer to children is significantly inferior" (p133), though it is not clear from the data presented, whether lack of subject knowledge or lack of confidence is more important, nor how such a generalisation can be supported on the basis of a sample of six teachers: that 'for teachers lacking adequate subject knowledge, the nature of the teaching and learning experience they offer children *can be* significantly inferior', is perhaps the most that could legitimately be claimed, but still begs the question of the criteria of adequacy and inferiority. They propose focusing on what teachers *can* do in order to set realistic expectations for future classroom practice, and conclude that "a curriculum which reduced its content whilst maintaining its breadth and balance, and placed more emphasis on investigative work would be more appropriate to the current skills and resources of existing teachers". (p140)

Millar and Driver (1987) argued against a process orientation in primary science, though they were primarily concerned with secondary science and did not attempt to justify the application of their arguments to primary ages. They equated 'process' with 'scientific method' with 'a set of rules', and argued that content and context distinguish science: processes are not characteristic. Hypotheses are 'scientific' if they "employ scientific concepts [and] seek to provide explanations of some part of the natural world" (p44) - but falsifiability, the fact that scientific concepts can be employed in poetry, and the fact

that much non-science also seeks to provide explanations of the natural world, are not mentioned. Nor is there any definition of what they mean by a distinctive 'context' of science, except a suggestion that it is a domain of experience (p51), and a possible example - learning to use a microscope (p42). They also argue that it is not possible to assess changes in a child's ability in process tasks on the grounds that performance on process tasks is not independent of content and context (p53). Such interdependence is important in the present study of primary teachers, and has clear corollaries (e.g. it is hard to measure 'content' independently of context and process skills); but the objectives of education will be rather limited if difficulty of assessment is to invalidate them. 'Process' abilities are seen as: general and given; not teachable; not progressive; not measurable or assessable. Further, two essential characteristics of scientific activity are not mentioned: its cumulative and its communal nature, in particular the key role of critical appraisal.

Later, Driver et al (1994) step back from personal constructivism, and acknowledge the social and discursive nature of scientific knowledge, learning as enculturation rather than discovery, and the co-existence of everyday representations with scientific explanations and reasoning. They find no simple rules for pedagogical practice emerging from a constructivist view of learning, and argue that negotiation with an authority is essential in two respects: to introduce new ideas or cultural tools where necessary, supporting and guiding students in making sense of them; and understanding the ways in which their teaching is being interpreted, to inform further action.

Smith and Neale (1989) offer evidence that teachers whose own competencies or views differ from those embodied in the curriculum, often dramatically adapt its sequence and content. They discuss what would be necessary for elementary teachers to teach 'conceptual change' science well, but conclude that 'there are no straightforward or simple answers' (p241).

Monk (1995) criticises constructivist research into pupils' beliefs on the grounds that it is too centred on the individual and 'microscopic', and suggests investigating progression through a broader brush approach which may better identify general trends.

Osborne (1996) also criticises both constructivist and 'official' lines in arguing that "an explicit treatment of the procedural basis of Western scientific knowledge is *essential* in science education .. the emphasis on declarative and propositional knowledge of which the British National Curriculum is a typical example, needs to be challenged". (p55)

Constructivism lacks a comprehensive account of the processes that help the individual generate new ideas and concepts, and transcend common-sense reasoning; Osborne argues that the limited theses of 'modest realism' (Hacking 1983, Harré 1986) have pedagogical implications quite distinct from those of constructivism. 'Modest realism' claims that: there is an ontological reality, to which scientific theories are human attempts to refer; theories are confirmable or falsifiable by evidence; and progression in scientific theories produces increasingly accurate approximations and descriptions of this reality. Echoing Kitcher (1993), Osborne argues that these provide a coherent scientific epistemology akin to that of practising scientists, and a theoretical basis for the construction of a curriculum, suggesting that early science education should build on children's experiences of macroscopic phenomena, introducing the descriptive language of science and theoretical frameworks which enable them to generalise from and re-interpret everyday experience; and that theoretical description should be introduced prior to observation and experience.

Hodson (1988, 1993) observes that rapid change in the science curriculum coincided with major developments in the philosophy of science (e.g. Popper, Kuhn, Lakatos, Feyerabend), but that "the former was uninformed by the latter, and the views of science methodology contained within the curriculum proposals were confused, frequently contradictory, and based on dubious or discarded philosophies of science .. There was too much emphasis on inductive methods, a too-ready acceptance of an instrumentalist view of scientific theory, a serious under-estimation of the complex relationship between observation and theory, and a neglect of the activities of the scientific community in

validating and disseminating scientific knowledge” (p22). He argues for construction of a curriculum along Kuhnian lines, with a pre-paradigmatic or pre-scientific stage occupying much of the time in primary and early secondary school, to establish the domain of science and build the prerequisites for studying science (order, causality, theoretical explanation of phenomena). He points out “inadequacies in the philosophical stance underpinning course design and in the implicit philosophies of science teachers. The former has led to philosophically invalid curricula, the latter to pedagogically invalid curricula .. [It is possible] to increase curriculum validity in both these areas through a consideration of basic issues in the philosophy of science and an analysis of the relationship between scientific knowledge, scientific methods, and the methods of learning science .. it would be a mistake to assume that this relationship is simple and direct.” (p35-6)

Howe (1996) discusses the development of science concepts within a Vygotskian framework, using ‘science’ in a broad sense to include concepts in the natural and social sciences, language, and mathematics, and associating scientific concepts with systematic, hierarchical knowledge as opposed to everyday experience’s non-systematic, unorganised, and context-bound knowledge: the crucial difference is the presence or absence of a system (c.f. Schutz and Bourdieu, cited in Solomon 1985 and 1994, discussed below). Vygotsky rejected Piaget’s underlying thesis that ‘development explains learning’: he held to the primacy of culture in shaping development, and took the view that teaching and nurture move ahead of development and are essential for it. Howe argues that Piaget’s influence on elementary science led to:

- focus on the internally driven mental activity of each child, hence to discovery learning, ‘hands-on’ science, and the teacher’s role as facilitator
- belief that cognitive development proceeds in universal, predictable stages, hence the child’s cognitive stage determines what can be learned and should be taught, within a rather narrow age range, regardless of experience, context or interest

- constructivism, and hence to enquiries into children's prior conceptions, and teaching strategies aimed at 'conceptual change', on the assumption that conceptual systems are or should be unitary, unambiguous, non-redundant, rather than pluralist, ambiguous and full of duplication and redundancy - an assumption that is untested and naive.

The implications of a Vygotskian perspective, on the other hand, are that:

- children should not be treated as solitary individuals trying to make meaning, but as participants in a joint enterprise in which meaning is derived through language-mediated interaction with other people: learning arises through the social interaction or discourse occasioned by activity, in which there is a central role for the teacher, rather than from activity itself
- the cognitive stage theory has been seriously challenged by research demonstrating the contextual nature and context-sensitivity of knowledge: thus context would be a prior consideration to cognitive demand in curriculum planning; and claims to transferability of science process skills are dubious
- a number of researchers (e.g. Driver et al 1994) now favour the merging of the constructivist/Piagetian and the socio-cultural/Vygotskian perspectives on learning, with implications for the role of the teacher, and the use of language to support and promote thinking, reflection, and bridging between contextual knowledge and broader conceptual systems.

Macaskill and Ogborn (1996) stress the importance of 'knowing how knowledge is made', emphasising the imaginative effort involved in the development of ideas, and arguing for something like the historical approach trialled by Solomon et al (1994). The present science curriculum 'in effect tells lies about what science is and about why pupils should study it' (p61).

Claxton (1991) calls for a radical review of science education: 'we do not have a problem with science education; we have a disaster with it' (p.vii). He insists that

it is vital that the long tentacles of the traditional induction into science proper do not reach down and twist what happens in the name of science in primary schools. The proper words for things, the proper way of measuring things, the proper format for writing things up - all these are premature, potentially intimidating and deadening, if imposed at this stage .. If they run up against problems of 'fair testing' or precise measurement, the last thing the teacher should do is solve them for them. Grappling with such problems is of the essence of science, and ingenuity is only developed in the struggle .. Their study should be built around the slowly gathering sophistication of three simple questions: How come?, So what?, and What if? These sum up the three processes of creative puzzlement, drawing out implications, and testing ideas through observation, that are at the heart of scientific thinking .. Their activities should involve chatting, looking for patterns, and messing about .. They do not need test tubes, and should be encouraged to undertake experiments whose products they can eat. Science should be muddled up with creative writing .. (p135)

Woolnough (1994) too warns that stressing content over process can lead to primary science being a 'watered down form of secondary science', arguing that science should be a holistic, not a reductionist, activity, involving the affective as well as the cognitive aspects of a student's life. The teacher must be concerned not only with what students know and can do, but also with whether they want to do it.

Solomon (1980) insists on the role of the imagination in science teaching and learning, seeing imaginative understanding as an essential prerequisite to successful experiment. She defends the social and consensual nature of science in the strongest terms:

However great the room we allow for invention and private research, however imaginative the fabric of scientific theory, it is not finally susceptible to individual interpretation because it has to be communicable knowledge .. this is not a matter on which a student may adopt a personal stance .. Science is a social activity and its images are as clear as, or clearer than, the vocabulary of any other language.

and points to the resemblance between science in the school laboratory and one of "the simplest and most basic types of learning - imitation, which involves

cultivating our pupils' thought by making it easy for them to understand our images and use our methods of reasoning. It involves showing and giving as well as trial and imitation - a commerce far more subtle than dogmatic instruction because it employs interpersonal communication and socialisation at a deep and valuable level (p149).

Solomon (1994), in criticising constructivism, makes crucial points about the varieties of, and by implication duplication and redundancies in, knowledge about the world:

Authors such as Schutz and Bourdieu had pointed specifically to formal over-arching knowledge systems, such as science or jurisprudence, as being at almost the opposite pole to life-world knowing. They also suggested that these two systems needed to co-exist in users' minds (p8).

There were occasional classroom reports which recognised the co-existence of two kinds of knowing, and saw teaching as a process of encouraging discrimination between them .. These arguments lined up with the work of Schutz and Bourdieu .. They too .. were swallowed down into the general vocabulary on constructivism with barely a spasm. It simply became normal to speak about the '*personal and social construction of knowledge*' (p11-12).

However these remain no more than nods in the direction of a pluralist model of knowing, the 'single-valued' nature of the curriculum and pedagogy being revealed by the on-going prevalence of talk of students' misconceptions and conceptual change (rather than talk of students' conceptions, connections, re-evaluations, and conceptual enrichment, that a pluralist model might imply).

2.5 Teacher thinking and professional identity

The preceding sections have looked at the views of the nature of science of various recent and contemporary philosophers of science, finding lively debate, a diversity of credible positions, and a blurring of the boundaries between academic and lay opinions; at the views of the general public, secondary science teachers and pupils, and primary teachers, finding a focus on the factual, pluralism, a lack of coherence, and a suggestion that primary teachers may be more in tune with contemporary philosophers of science than

either secondary science teachers or working scientists; and at educationalists' views on primary science education, again finding lively debate and various grounds for dissatisfaction with the status quo.

This review of the relevant literature concludes with a survey of some philosophical considerations and research findings on teachers' thinking, knowledge, confidence and professional identity. These reveal such a subtle network of influences and interdependencies that any simple model cannot but be called into doubt, echoing Merton's (1975) doubts about "prescription of a single theoretical perspective that promises to provide full and exclusive access to the sociological truth". Merton advocates "a plurality of theoretical orientations .. in the form of a 'disciplined eclecticism'" (p51): while Shulman (1981) rebuts the notion that educational research is in a Kuhnian pre-paradigmatic stage, arguing that "our plurality of theories is not an artefact of transient immaturity but an inevitable feature of our disciplines. Theoretical pluralism is our mature state."

2.5.1 The importance of identity

Helms (1998) defines the self - "the experienced self in context" - as having four dimensions, each of which "can pertain to professional and personal issues": actions; expectations, which may be institutional, cultural, social - "what people think others expect"; values and beliefs; and direction, "where people see themselves going, or the kind of people they want to become" (p829). This "becoming" may be prompted by a "perceived deficiency or ... perceived possibility" (p830), and provides "... a foundation that anchors the personal dimensions of identity ... a sense of becoming lends connectivity to our actions, beliefs, values, and our sense of what others expect of us" (p831).

Her research with secondary science teachers has shown that "teachers have more than a passing intellectual interest in their subject matter - in fact, dimensions of their identities are, to greater or lesser degrees, defined by it; or, at the very least, they construct an identity in direct relation to science. Establishing the nature of science was not simply a

philosophical exercise, but an attempt to understand more about themselves ... who they are, why they do what they do, and ... who they want to become” (p831).

Much of a professional’s knowledge is essentially tacit (Polanyi 1958) for much of the time, but can become explicit through a kind of ‘cultural confrontation’ as envisaged by Bourdieu (1977):

‘If the emergence of a field of discussion is historically linked to the development of cities, this is because the concentration of different ethnic and/or professional groups in the same space, with in particular the overthrow of spatial and temporal frameworks, favours the confrontation of different cultural traditions, which tends to expose their arbitrariness practically, through first-hand experience, in the very heart of the routine of the everyday order, of the possibility of doing the same things differently, or, no less important, of doing something different at the same time; and also because it permits and requires the development of a body of specialists charged with raising to the level of discourse, so as to rationalise and systematise them, the presuppositions of the traditional world-view, hitherto mastered in their practical state.’

Solomon (1994) pursues the plurality of perspectives from which each individual sees the world, referring to Schutz’ and Bourdieu’s view of “formal over-arching knowledge systems, such as science or jurisprudence, as being at almost the opposite pole to life-world knowing. They also suggested that these two systems needed to co-exist in users’ minds”(p8). She argues (1997c) that through exercising choice humans not only demonstrate but create their personality: “every time we choose to act in a certain way, we not only define, but also re-define, both publicly and to ourselves, the identity of that person that we are always in the process of becoming”, and points out that numerical data “cannot serve to explain psychological effects since they neither describe and analyse the act of choosing, nor gather reflections on the choice after it is made. We need to reflect much more on ideas like the construction of personal choosing, and cultural persuasion”. It might also be suggested that we choose not only how to act, but also to some degree how to see, and from what perspective we view the world.

Solomon has also argued (1997b) for a pluralistic model of selfhood, and against the notion of an individual's holding a world-view which subsumes "all kinds of knowing, along with religion, gender, ethnicity... the social forces which shape selfhood through such means as solidarity with a range of groups in different places at different times, cannot produce a unique or stable world-view... people exhibit multiple identities or roles to cope with the variety of views they meet at work, at home, and on television."

Taking a systemic approach, and drawing heavily on the work of Prigogine, Maturana and Varela, Capra (1996) sees mind, self and self-awareness as examples of emergent processes of (hierarchies or networks of) autopoietic networks, characterised by structure (the physical embodiment of a system), pattern of organisation (the relationships determining the system's essential characteristics), and process (the continual recreation of structure within the pattern of organisation). Although not specifically addressed by Capra, it will be argued later that identity can be understood as another such emergent process.

Giddens (1991) and Harré (1983) are concerned with the nature and ontogeny of personal identity. Harré positions this concept as follows: there are three 'ways of being': the social, the personal, and the physical. Within personal being there are three types of unity: the formal unity experienced as consciousness, with a reflexive form of self-consciousness; the practical unity of agency, with a reflexive form of self-mastery; and the empirical unity of identity, with a reflexive form of autobiography. He prefers to account for psychological phenomena in terms of modes of reasoning and systems of belief rather than the 'automaton theories' of cognitive psychology, unless there is specific justification to do otherwise, and sees mind not as an entity, but as 'a system of beliefs structured by a cluster of grammatical models' (p20). The sense of personal identity grows out of the realisation that one has a point of view from which the choice to act is constructed. The two primary realities in human life are the array of persons within which the individual is situated, and the network of 'symbiotic interactions' that appear as two secondary realities, the social system of material production, and the creation and maintenance of honour and value, both of which are mediated by meanings and stabilised

by ritual and routine. Thought, he argues, is the ‘privatisation and personalisation’ of this symbiotic network (p20-21).

Giddens also sees self-identity as a changing creation, not only adapting to external conditions but also incorporating them, and reflections on them, into an autobiography:

Self-identity is not a distinctive trait, or even a collection of traits, possessed by the individual. It is the self as reflexively understood by the person in terms of her or his biography..... This includes the cognitive component of personhood. (p53)

Similarly, Lave and Wenger (1991) argue that learning involves ‘the fashioning of identity’ and the reconstruction of life story (p79-80), and Taylor (1985) stresses the emergence of identity within a community of discourse, without which human agency “would not just be impossible, but inconceivable” (p8). Agency, sense of self, personal history, purpose, imagination, an evaluative capacity, and a capacity to make and implement choices, together with participation in a community of discourse, are what constitute a person. He describes man as a ‘self-interpreting animal’, not only with a compulsive tendency to form reflexive views of himself, but also “partly constituted by self-interpretation, that is, by his understanding of the imports which impinge on him.” (p72)

These understandings of identity provide a theoretical infrastructure for both an autobiographical mode of enquiry, and for making a meaningful interpretation of statements beginning, for example, “I think...”.

2.5.2 Professional development

Various families of views of teacher professional development are outlined below:

- modes of adjustment or adaptation varying in degree of autonomy, as described by Lacey
- movement through a hierarchy of change, at the top of which is change in practice, as for example in Harland and Kinder’s account
- *development through practice*

- development through reflection on practice.

These are complementary perspectives rather than competing hypotheses. In considering them, it may be useful to bear in mind two ideas.

Firstly, the notion that all professional development takes place on a foundation of or in a context provided by the life experiences of the person becoming a teacher, including the lay theories (Holt-Reynolds, 1992) that they bring with them from their personal and cultural biographies, and which constitute some of the “most formative personal and social influences on their professional identities” (Sugrue, 1996, p155).

Secondly, the evolutionary epistemology developed by Campbell (1960, 1974), which describes the ‘natural selection’ of ideas and images with both good fit and corrigibility. This implies an epistemological dualism (where beliefs are distinct from referents, and the notion of degree of fit makes sense), and a critical realism (commitment to the reality of an external world, acknowledging the imperfection of beliefs about it). Campbell argues that there is only one explanatory paradigm available for the problem of fit - blind variation and selective retention: weak, slow and improbable mechanisms, accepted because they describe a possible route and there are no rival explanatory theories.

Hierarchical structures require hierarchical replications of the selection process, with ‘a node of selection for every emergent level of organisation’: common to any ‘selection’ theory must be undirected variation, systematic selection, and retention of selected variations. Lack of any one component will mean that there is no increase in fit or order. This approach may provide an explanation of the necessity of practice and reflection in professional development, as both provide opportunities for generation and selective retention, and an insight into possible mechanisms.

2.5.2.1 Professional development through adaptation

Lacey (1977) describes three ways that newly qualified teachers might adjust to teaching: internalised adjustment, strategic compliance, and strategic redefinition. He writes: “..the actor has a choice with respect to the social strategy he employs. He can internalise all the supporting arguments and values - internalised adjustment - or he can ‘get by’ and

remain only partially convinced by them - strategic compliance. Beyond this, he can attempt to wrestle with the constraints of the situation and in a sense hold the institution at bay - strategic redefinition. Most strategies of this sort are highly dependent on the skill and commitment of the individual and persistent failure to redefine the situation from a position of weakness .. can lead to serious problems.” (p96) These choices will influence how a teacher develops as a professional, in particular the degree of autonomy that they take or achieve, with regard to their own professional development.

2.5.2.2 Professional development through hierarchies of change

Harland and Kinder (1997) discuss what changes in the course of professional development. They identify a range of types of outcome from professional development courses, from the mundane (e.g. worksheets, facts, news), through insights and new awareness (e.g. that science is not about “chemical formulae and test-tubes, but about children investigating”, development of new knowledge and skills), to personal and institutional change and growth (e.g. of value congruence, increases in self-confidence, changes to the teacher’s ‘self-concept, their occupational identity’, and development of consensus and shared meanings), and ultimately to changes in professional practice. Extending the ideas of Joyce and Showers (1984), they argue for a hierarchy of change, at the top of which is change in classroom practice; and that change in classroom practice cannot be brought about directly, but only through change lower down the hierarchy.

Joyce and Showers themselves saw a progression in the levels of outcome of professional development activities, from a lowest level of raised awareness, through to a highest level of becoming fully competent in classroom practice; and a parallel progression in approaches to training, from a lowest level of attending a lecture or talk, through to a highest level of mentored or supported implementation of new skills in a classroom context, through individual coaching and feedback. They reported that the highest levels of outcome required a co-ordinated approach at all levels of training; and that training at the lower levels was unlikely to be associated with outcomes at the higher levels of practice.

Eraut (1988) throws an interesting sidelight on teacher knowledge by discussing the knowledge domains used by school managers. He identifies six interdependent, non-exclusive, non-exhaustive categories of knowledge organised into a rough three-level hierarchy, namely:

- knowledge of people, situational knowledge, and knowledge of educational practice (policies, strategies, actual and proposed practices)
- conceptual knowledge (theory of education and management, concepts and frameworks for thinking) and process knowledge (how to get things done ... including conventionally defined 'management skills')
- 'control knowledge' (self-knowledge, meta-cognitive skills, control and use of one's own knowledge).

2.5.2.3 Professional development through practice

Russell (1988) describes a developmental trajectory for professional growth as 'beginning by mastering a program at the level of practice, then moving from comfort with practice to criticism of practice, using theories acquired by studying how subjects are learned' (p19). Davies' (1998) study looked at student primary teachers' learning about science by the use of various 'learning tools' (i.e. direct teaching; distance learning; collaborative learning; modelling ideas; practising operations (e.g. doing past SATS papers); classroom experience), and compared levels of use and student-rated usefulness. Levels of use reflected ease of access: in descending order (most used first): distance learning, direct teaching, practising operations, modelling ideas, collaborative learning, classroom experience. Perceived usefulness/helpfulness was (most helpful first): classroom experience, modelling ideas, collaborative learning, direct teaching, practising operations, distance learning, reflecting closeness to the classroom. "That classroom experience was felt by many students to be the most successful way of developing scientific knowledge to teach should hardly surprise us. These people are, after all, training to be primary teachers rather than professional scientists. Subject

knowledge is important, but pedagogic subject knowledge needs to have pride of place in primary science teacher education.” (p10)

2.5.2.4 Professional development through reflective practice

Schön's (1983) critique of “technical rationality”, and development of the idea of reflective practice, has been enormously influential in research and practice in teaching and teacher education. Technical rationality, described by Schön as “the dominant epistemology of practice” in professional contexts, is “instrumental problem solving [purportedly] made rigorous by the application of scientific theory and technique” (p21): a central notion is the existence of a systematic knowledge base of the profession which is “specialised; firmly bounded; scientific; and standardised” (p23); and which consists of general principles that can be applied to concrete problems. His alternative is a reflexive dialectic between practice and theory mediated by the experience and reflections of the practitioner on problem and role frames and conflicts between them, repertoire building, fundamental methods of inquiry, and overarching theories, a process in which theory and associated method are used to restructure what is going on so that the practitioner can explain it: this kind of restructuring can actually constitute explanation, and the restructured material can be appropriate to the kind of intervention that the practitioner can readily undertake. This analysis suggests two kinds of foci for reflection: to look at how processes of recognition and restructuring work by examining episodes of practice, and “action science”: looking at unique, uncertain, unstable situations “which do not lend themselves to the application of theories and techniques derived from science in the mode of technical rationality” (c.f. Shulman 1986 - “strategic research sites” or “key events” for illuminating how knowledge grows in teaching) and develop “themes from which .. practitioners may construct theories and methods of their own” (p319). Doing this, individuals can build their own theories-in-action with “optimal fuzziness”, useful imprecision.

Researching the process of reflection-in-action is problematic: it is influenced by cognitive, affective, and group dynamic effects; and to study it we must observe

someone engaged in action. Schön suggests three research models: the researcher sets tasks for performance by the practitioner; the practitioner carries out self-set tasks, and the researcher tries to learn about how the practitioner is thinking and acting by e.g. a 'think aloud' approach, sometimes known as 'protocol analysis'; or the combination of research and intervention: as Schön points out, often just asking a question such as "how are you thinking about it now?" becomes an intervention which changes the direction of action and the practitioner's understanding and perspective. "Hawthorn effects are unavoidable": the researcher is part of social context, is an "agent-experient" who must "try to become aware of his own influences on the phenomena" (p322), and the relationship of researchers and practitioners is very different from that in applied science. The practitioner is not a mere a mere supplier of data, nor a mere user of research output - reflective research is a partnership.

Carr (1982) adopts a hard line on the validity of educational research: "There are no 'educational phenomena' apart from the practice of those engaged in educational activities, no 'educational problems' apart from those arising from these practices and no 'educational theories' apart from those that structure and guide these practices" ...the only task that educational theory can legitimately pursue is "to develop theories of educational practice that are intrinsically related to practitioners' own accounts of what they are doing" ... such theories can help teachers to improve their practice by transforming the ways in which practice is experienced and understood, but this transformation depends on teachers' capacity for critical reflection. The problem is to help teachers to 'see' what is happening in the everyday world of their classrooms in order to reflect, and solving this problem is the role of educational research.

Brown and Angus (1997) discuss the long-term nature of teachers' professional development, identifying three pre-requisites for fulfilment of potential: the need to remain up-to-date in both pedagogy and discipline; sufficient autonomy to exercise professional judgements, through which they reflexively develop a sense of pedagogy and understand the complexity of the relationship between teaching and learning; and developing a process of critical reflection on the outcomes of practice, which can occur

both individually and collectively and may be formal or informal. "Teachers' talk about practice represents a critical point at which theory and practice intersect, and where teachers, as practitioners, generate personal insights and contribute to the shared understandings of what constitutes good practice." p45

Calderhead has worked extensively in the areas of teacher thinking, professional development and reflective practice. His early work showed how professional development results in enriched conceptual structures, distinctions and repertoires of responses to situations (Calderhead 1979), and his goals for 'reflective' teacher education include

- enabling teachers to analyse, discuss, evaluate and change their own practice and appreciate the social and political context in which they work, and the moral and ethical issues implicit in classroom practices
- encouraging teachers to take more responsibility for their own professional growth, and to develop their own theories of educational practice
- empowering teachers to better influence the future directions of education (Calderhead 1993).

He recognises the importance of teacher's early conceptions of teaching, which are formed as a pupil: "the need to learn that they need to learn, and how to do it"

(Calderhead 1988, 1991), and the centrality of images, scripts, routines or rules of thumb in the nature and role of practical knowledge (Shank and Abelson, 1977; Elbaz, 1983; Calderhead and Robson, 1991; Calderhead, 1998). He describes various levels of abstraction of images, from the very high (e.g. an infant teacher has an image of "classroom as home", a powerful metaphor shaping thinking about teacher-pupil relationships and roles, classroom 'atmosphere' and organisation .. an image at this high level of abstraction has "strong affective connotations, and is associated with powerful beliefs and feelings of what are 'right' ways of teaching, rooted in past life experiences" - see Clandinin 1986); lower level images such as images of the 'ideal' teacher, or of different types of teaching, again derived from the teacher's own experiences as a pupil

or student; and lower still, images of particular lessons or activities, typifying how these usually run, e.g. mental arithmetic, spelling tests, the image serving to associate a known set of preparatory and management tasks and a known set of children's behaviours and responses.

Calderhead sees learning to teach as involving the accumulation and use of such images, but it "cannot be explained purely in terms of modelling, or image accumulation" ... models are not universally applicable, but have to be selected and adapted for particular situations. Higher order cognitive processes, or meta-cognition - thinking about, evaluating, structuring, comparing and developing images of practice for particular situations and contexts - have also to be developed. "One could ... hypothesise a series of meta-cognitive skills that structure experience to make it instrumental and applicable for action." The role of discipline content knowledge is seen equivocally: student teachers with good content knowledge still draw more on "observed practices of their supervising teacher" ... "translation of subject matter knowledge into practice requires interaction between this knowledge and other knowledge such as that concerning children or teaching strategies ... those interactions are highly complex ... a good science teacher ... or ... science co-ordinator, is not necessarily a teacher with a strong science background ... a teacher with a lot of art and craft or drama experience can sometimes come to grips more readily with the creative processes of teaching and learning primary science ... the scientist with a large store of subject matter knowledge, perhaps much of it taken for granted, may find it difficult to foster experimentation and enquiry at the primary school child's level. The scientist's knowledge may also sometimes be associated with images of teaching and learning quite contrary to those appropriate for the primary school" (Calderhead 1988, p57-8).

He attempts to "conceptualise the professional learning process", proposing a model where "conceptions of learning to teach" drive meta-cognitive processes that draw on and reflexively change the same set of knowledge sources and a body of practical knowledge, out of which flows classroom practice: the meta-cognitive processes are described as "abstraction, comparison, analysis and evaluation that operate on different

images of practice or on a variety of knowledge bases to generate usable practical knowledge". For example, abstraction of typifications or exemplars of what 11-year-olds are like, individually and collectively, from wide and varied bodies of developmental, learning, experiential etc. knowledge; or, planning using several meta-cognitive skills and several databases including subject matter, pupils, teaching strategy, classroom management, material context, resource knowledge, etc.

Beyond meta-cognitive skills, Calderhead hypothesises "a further organising structure" influencing how knowledge is developed and used. In initial teacher education, the conception of the process of learning to teach may not always be clear, and may be implicit in a student's approach to learning, but will "influence the type and extent of meta-cognitive skills that are employed", so that for example assessment-oriented students are likely to focus on 'proper' teaching actions even when inappropriate; students for whom learning is a linking of theory and practice will develop meta-cognitive skills focused on interrelating theory and practice; and those viewing learning to teach as a process of imitation may develop few meta-cognitive skills, adopting fairly uncritically the actions of their supervising teacher (Calderhead 1988, p61-2).

He stresses how heavily teaching relies on the images of practice acquired from past and current experiences in schools, which can be taken and implemented uncritically, and suggests that some difficulties "might be attributed to particular models of professional learning which have become implicit in teacher education and which fail to acknowledge the nature and use of knowledge in teaching", especially the differences between *academic and practical knowledge, the role of meta-cognitive skills in the generation, structuring and use of knowledge, and the influence of the learner's conceptions of learning on meta-cognition.*

Consistent with the above are Ruddock's (1988) attempts to link the 'biographical approach', professional development, and curriculum change. She argues that commitment to change both demands and arises from reflection on one's own experience of school, higher education, and teaching, and on the views of knowledge and learning

thus engendered: teachers who “own the problem of change” recognise and are prepared to deal with dissonance between such understanding and practice. In describing feelings in schools in the late 1980’s, she contrasts the low morale and dissatisfaction of experienced teachers with the positive self-image and spirit of new entrants who retain a sense of mission despite staffroom culture, and argues that “teachers need to understand the structure of their own readiness for change, or the basis of their own resistance to it” (p212-3).

Though acknowledging the role of the working group in effecting change, she stresses the importance of individual members’ own commitments and self-understanding, arguing that the teacher facing change needs to construct two landscapes: the landscape of consciousness (essentially about personal meanings) and the landscape of action (the locus of political struggles needed to bring about change), and proposes that one role of educational research is to “help teachers with the task of constructing their own landscapes of consciousness”. Ownership of change implies a personally founded motivation towards change, based on meanings explored in relation to the self as well as in relation to the professional situation: “professional learning is ... more likely to be powerful in its engagement with fundamental issues in education if teachers have constructed their own narrative of the need for change. This view .. reaches across to critical theory as a basis for professional learning, and recognises that in situations where routine and the reproduction of sameness are prevalent, practitioners need help in getting a grasp of the worthwhile problematics of teaching”. Degree of liberation is proportional to degree of freedom to choose from a range of perspectives of the self and the social world, requiring appreciation of the problematic, socially constructed, and socially and politically influenced nature of one’s views of what is good, right, true, possible, etc. If teachers can achieve and sustain such a perspective, “they can take on the role of powerful ‘intellectuals’ rather than be merely ‘minor technicians’” in curriculum battles as they are played out, and through their own professional development, they can develop their profession.

Solomon and Tresman (1999) describe a model of 'continual professional development' that draws together much of the above. They characterise professionalism as holding values that transcend practice, and that outweigh all else, including subject knowledge, as prerequisites for confident teaching. They ascribe the continuing construction of self-image to reflection on professional action based on reconstruction of episodes from the classroom, informed by professional development activities, in a cycle which establishes a professional identity on which the teacher's honour, values and beliefs depend.

2.5.3 Teacher knowledge

In the mid-1980's, Lee Shulman of Stanford University framed a discourse of teacher knowledge that has had a widespread influence since, in educational research: hence this section explores his ideas in some detail, before looking at other angles on teacher knowledge.

2.5.3.1 Shulman's 'knowledge growth in teaching' research programme

Shulman (1984, p191) argues that, to the extent that teaching is an art, its practice requires at least three forms of knowledge: 'knowledge of rules, knowledge of particular cases, and knowledge of ways to apply rules to cases.' Particular cases, and ways to apply rules to cases, are addressed to only a very limited extent in teacher education - by teaching practice or internship - but 'the selection and range of cases is restricted to the particular classroom in which the internship occurs'; and 'not even a modestly systematic attempt is made to provide the novice teacher with a representative array of prototypic cases'. Schön (1983) makes a similar point in relation to professional education in general. In his influential 1986 paper, Shulman explores how subject matter is transformed from the knowledge of the teacher into the content of instruction, and "how particular formulations of that content related to what students came to know or misconstrue (even though that question had become the central query of cognitive research on learning)", and describes a research programme into 'knowledge growth in teaching' which attempts to trace the "intellectual biography - that set of understandings, conceptions and orientations that constitutes the source of their comprehension of the

subjects they teach” of a group of teachers. He suggests (p9-10) three categories of *content knowledge*:

- subject matter content knowledge - may be analysed/represented by “Bloom’s cognitive taxonomy, Gagne’s varieties of learning, Schwab’s distinction between substantive and syntactic structures of knowledge”
- pedagogical content knowledge: extension of content into the ‘teaching dimension’: useful representations of ideas, analogies, illustrations, examples, explanations, demonstrations; an understanding of what makes learning specific topics easy or difficult; conceptions, pre- and mis-conceptions *that particular types of students bring*; fruitful strategies for reorganising and transforming pre- and mis-conceptions: Shulman stresses the potential contribution of cognitive research on learning to this category
- curricular knowledge: ways of presenting/teaching a topic.

He maintains that, if this description of content knowledge were to form the basis of professional exams, it could distinguish between someone who ‘majored’ in a subject and someone able to teach it, “*in a pedagogically relevant and important way. It would be much tougher than any current examination for teachers.*” He describes (p10) three forms in which each of these categories of knowledge may come:

Propositional knowledge: much of what is taught to teachers is in this form: as are results of research and the accumulated lore/wisdom of practice: propositions work best when groups of them are organised according to some conceptual framework. Shulman identifies three types of propositional knowledge, corresponding to three sources of knowledge:

- principles - coming from disciplined empirical or philosophical inquiry - e.g. “Ordered turns are associated with higher achievement gains than are random turns in first grade reading groups”

- maxims - from practical experience - e.g. make five-step lesson plans; never smile till Christmas; organise three reading groups
- norms - from moral or ethical reasoning - e.g. give each student equal opportunities/fair turns; do not embarrass people in front of their peers.

Problems with propositional knowledge are that it is hard to remember, in large quantities, therefore “theoretical frameworks as intellectual scaffolding become essential”: and that since conciseness demands minimal detail, propositions are decontextualised - but wise use demands detail and context.

Case knowledge: to call something a case is to make a theoretical claim - that it is a case of something, an instance of a wider class, used to illuminate theory and practice: “knowledge of specific, well-documented, and richly described events”. He describes three types corresponding to the three types of propositional knowledge above:

- prototypes exemplify principles
- precedents “capture and communicate principles of practice or maxims”
- parables convey norms or values.

A given case can have one or more of these roles, e.g. “the box of short pencil stubs” (for giving out to students who arrive at a lesson without writing implements) is a “fine classroom management precedent”, but is also “a memorable prototype for the principle of avoiding reinforcement of maladaptive behaviour”. Cases serve as a basis for analogical reasoning, and can be more memorable - because they are organised as stories. Shulman quotes Geertz (1983) in support of qualitative research “directed at cases or sets of cases, with particular features that mark them off”, and argues (p12) that “generalisability does not inhere in the case itself, but in the conceptual apparatus of the explicator. An event can be described; a case must be explicated, argued, dissected, and reassembled ... there is no real case knowledge without theoretical understanding. What passes for atheoretical case knowledge is mere anecdote, a parable without a moral.”

Strategic knowledge: real-life problems often call into play conflicting principles, *maxims*, etc. For example “longer wait times produce higher levels of cognitive processing” conflicts with “too slow pacing leads to discipline problems”: hence “principles collide and no simple solution is possible” (p13). Knowledge of relevant propositions and cases forms the underlying knowledge base: “Strategic knowledge must be generated to extend understanding beyond principle to the wisdom of practice”.

Shulman envisages methods of instruction that involve “the careful confrontation of principles with cases, of general rules with concrete documented events - a dialectic of the general and the particular in which the limits of the former and the boundaries of the latter are explored ... What distinguishes mere craft from profession is the indeterminacy of rules when applied to particular cases ... reflective awareness of how and why one performs complicates rather than simplifies action and renders it less predictable and regular”.

Shulman’s (1987) idea of teaching emphasises comprehension, reasoning, transformation and reflection - aspects “blatantly ignored” by past research and policy. He addresses four questions:

1. what are the sources of the knowledge base for teaching?
2. in what terms can these sources be conceptualised?
3. what are the sources of pedagogical reasoning and action?
4. what are the implications for teaching policy and educational reform?

The sources of knowledge include:

- scholarship in content disciplines, founded on accumulated literature and the “historical and philosophical scholarship on the nature of knowledge in those fields of study”. Teachers must understand (p.9) “the structures of subject matter, the principles of conceptual organisation, and the principles of inquiry that help answer two kinds of questions in each field: What are the important ideas and skills in this domain? and How are new ideas added and deficient ones dropped by those who produce knowledge in this area? That is, what are the rules and procedures of good

scholarship and inquiry? These questions parallel what Schwab (1964) has characterised as knowledge of substantive and syntactic structures, respectively.” The teacher conveys, whether consciously or not, by the manner in which they communicate the subject matter, ideas about what is essential and what peripheral in a subject, what counts as ‘truth’, attitudes and values that mediate student understanding. This “places special demands on the teacher’s own depth of understanding of the subject matter”, and their “attitudes toward and enthusiasms for what is being taught and learned.”

- educational materials, structures, institutional settings, including curricula; assessment and testing material; institutional hierarchies, implicit and explicit rules and roles, teachers’ organisations, local and central government agencies and mechanisms of governance and finance
- research, scholarship in education and related areas: Shulman argues that “the normative and theoretical aspects”, which enrich teachers’ images of what is possible, are the most important, and criticises policy-makers for over-reliance on limited empirical findings
- “the wisdom of practice”: “the maxims that guide (or provide reflective rationalisation for) the practices of able teachers. One of the most important tasks of the research community is to work with practitioners to develop codified representations of the practical pedagogical wisdom of able teachers” (p11-12), in accounts that should be highly contextualised.

He contrasts teaching with other professions in its “extensive individual and collective amnesia, the consistency with which the best creations of its practitioners are lost to both contemporary and future peers, the lack of an equivalent of ‘case law’, the absence of ‘an audience of peers’”... but claims that extensive codifiable knowledge can be “gleaned from the wisdom of practice” and sets a research agenda “for the next decade .. to collect, collate, and interpret the practical knowledge of teachers for the purpose of establishing a case literature and codifying its principles, precedents, and parables”, and

predicts evolution of the structure and content of the teaching knowledge base: “Our current “blueprint” ... has many cells or categories with only the most rudimentary placeholders”.

Turning his attention to the processes of pedagogical reasoning and action (p12-19), Shulman emphasises “teaching as comprehension and reasoning, transformation and reflection”: the goal of teacher education is to enable teachers to “reason soundly about their teaching as well as to perform skilfully .. sound reasoning requires both a process of thinking about what they are doing, and an adequate base of facts, principles, and experiences from which to reason .. it’s one thing knowing, it’s another using knowledge to make choices and to act effectively: this has to be learnt”. He sees teaching as starting with the teacher’s comprehension of some form of ‘text’ - a book, syllabus, etc. His model of pedagogic reasoning is iterative and not as straight-line as the presentation makes it appear (p.15): steps can happen in various orders, be repeated, omitted, truncated, elaborated, and supplemented with other steps. The steps are as follows:

- Comprehension: by the teacher, of purposes, subject matter structure, ideas within and outside the discipline
- Transformation: the essence of pedagogical reasoning, involving:
 - preparation: critical interpretation and analysis of texts, structuring and segmenting, development of curricular repertoire, clarification of purposes
 - representation: from a repertoire including analogies, metaphors, examples, demonstrations, explanations, etc.: Shulman links this to cognitive psychology’s internal representations e.g. Gardner (1986) claims a key accomplishment of cognitive science is its identification of levels of mental representation, “a set of constructs that can be invoked for the explanation of cognitive phenomena”
 - (instructional) selection: from an instructional repertoire including lecture, demonstration, recitation, deskwork, forms of co-operative learning, reciprocal

teaching, Socratic dialogue, discovery learning, project methods, and learning outside the classroom setting

- adaptation and tailoring to student characteristics: adaptation to typical groups of or individual students, tailoring to specific groups or individuals: considering (pre-, mis-)conceptions, difficulties, language, culture, motivation, social class, gender, ability, age, aptitude, interests, self-concepts, attention
- the result of this transformation process is a plan ... pedagogical reasoning continues during instruction, and “is as much a part of teaching as the actual performance itself.”
- Instruction: “management, presentations, interactions, group work, discipline, humor, questioning, and other aspects of active teaching, discovery or inquiry instruction, and the observable forms of classroom teaching”. There are “compelling reasons to believe that there are powerful relationships between the comprehension of a new teacher and the styles of teaching employed”.
- Evaluation: checking, assessing, testing students’ understanding during and at the end of lessons and units: “to understand what a pupil understands will require a deep grasp of both the material to be taught and the processes of learning”.
- Reflection: “reviewing, reconstructing, re-enacting and critically analysing one’s own and the class’s performance, and grounding explanations in evidence.”
- New comprehensions: “of purposes, subject matter, students, teaching, and self; consolidation of new understandings, and learnings from experience”.

In an abstract way it is possible to see Shulman’s theory as a complex network of entities, processes, and sub-networks, all of which evolve through cyclical processes of comprehension, transformation, teaching, evaluation, reflection, and new comprehension - not least of which could be the developing comprehension of professional self, of identity as a teacher, though notions of this ‘holistic’ kind do not figure in Shulman’s essentially reductive analysis. His emphasis is on the structure and

structural components of teacher knowledge - a full systemic account would give equal weight to organisation and process (Capra 1996) - and his unspoken assumption is that one can talk about 'teacher knowledge' in such a general way, as if a universal structure, organisation and process could be abstracted, which would be common to all teachers.

2.5.3.2 Other angles on teacher knowledge

Harlen and Holroyd (1997), reporting on an investigation of the problems relating to background knowledge and confidence among Scottish primary teachers, in science and technology teaching, found that some ideas presented few problems, while others required extensive in-service training. As well as their understanding of the subject matter, confidence was influenced by the teachers' own school and personal experiences; the nature of their initial and in-service training; the experience of pressure and curriculum overload; the support available from colleagues and materials resources; teachers' views of their professional capability (p102). These were sometimes more important than subject knowledge. Teachers with low levels of confidence were found to employ a variety of strategies for coping, "some of which when regularly applied have a severely limiting effect on children's learning" (p93). Harlen (1997) reviews the extensive research on the scientific ideas of primary teachers, and the impact of deficiencies in subject knowledge on practice, warning that before jumping to the conclusion that the solution is "to put teachers through a science course, we need to understand the role of subject knowledge in primary teaching. This role is surely not to answer all the questions that children ask. Instead it is to enable them to ask questions that lead children to reveal and reflect on their ideas, to avoid 'blind alleys', to provide relevant sources of information and other resources, and to identify progress and the next steps that will take it further. These things cannot be done if teachers do not understand the ideas they are aiming for. However, they require understanding of broad principles and key ideas rather than a knowledge of detailed facts." (p8) It might also be suggested that these are things which, for the most part, *can only be developed in practice*.

Davies' (1998) study reinforces this point. He investigated student teachers' use of, and their perceptions of the relative contributions of, the various components of the "learning toolkit", to their development as teachers. The toolkit was defined as: direct teaching; distance learning; collaborative learning; modelling ideas; practising operations (e.g. doing past SATS papers ..); and classroom experience. Unsurprisingly, level of use largely reflected ease of access: in descending order (with the most used first): distance learning, direct teaching, practising operations, modelling ideas, collaborative learning, classroom experience. Perceived usefulness/helpfulness was (most helpful first): classroom experience, modelling ideas, collaborative learning, direct teaching, practising operations, distance learning. Davies comments: "That classroom experience was felt by many students to be the most successful way of developing scientific knowledge to teach should hardly surprise us. These people are, after all, training to be primary teachers rather than professional scientists. Subject knowledge is important, but *pedagogic subject knowledge* needs to have pride of place in primary science teacher education" (p10), and this again can only develop through practice.

Another angle on the relationship between subject knowledge and confidence is provided by research findings from Appleton (1995), who showed that student teachers who mastered only a small area of curriculum knowledge in the physical sciences, acquired an increased confidence in teaching science across the board. He deduced that it was not knowledge alone that produced confidence, and identified the development of a positive self-image as a science teacher as a primary goal of teacher education.

Calderhead's (1984) focus on teachers' classroom decision-making is therefore apposite, in that it is the locus for this crucial strand in the development of professional knowledge and identity. He sees teaching as consisting of the design, implementation and maintenance of activities; and teacher thinking or decision-making as varying depending on its timing (pre-active or interactive) and mode (reflective, immediate or routine). Thinking that is pre-active and reflective is directed at the design and sequencing of activities. That which is interactive, and immediate or routine is concerned with implementing a design and maintaining activities. Calderhead points out that on average a

primary teacher makes around 300 decisions per hour, most of which must of necessity be routine. Constraints on teachers and their thinking arise from physical sources (such as class size and composition, materials, space), ideological sources (beliefs, values, expectations about content and method), and the broader context, such as the socio-economic background of the school and its pupils, funding, characteristics and history of the head, governors, parents, pupils, examination boards, syllabi, and the curriculum.

Inputs to teachers' planning are identified as the curriculum, institutional expectations, and the teacher's own beliefs and ideologies of education. The main planning task is seen as lesson planning: deciding on subject matter and activities, in the context of pupils' abilities and possible reactions to subject matter and what they will be asked to do: long-term planning is seen as an "inefficient and unconstructive use of time". Two planning styles are distinguished: incremental (little advance thought, close contact with pupils, focus on their day-to-day development), and comprehensive (planning of lessons and their place in the whole course, clearer objectives. Teachers are said to have a preferred style but to switch with circumstances, e.g. incremental is favoured for unfamiliar activities and pupils. There is some evidence of a link between a high ability to conceptualise and a focus on pupils and the instructional process in planning, compared with a low ability to conceptualise and a focus on "low-order subject matter". For experienced teachers lessons are frequently based on variations on well-established models, and most of their planning is 'tweaking' of 'routines'. This can lead to problems in curriculum innovation: see Doyle and Ponder's (1977) account of how teachers approach innovation as 'pragmatic sceptics' within the frame of a 'practicality ethic' of three criteria: instrumentality (is it suitable for immediate classroom implementation?); congruence (with teacher's normal style, types of pupil, pupil expectations, working context); and cost (in time, effort, money) versus benefit (in learning, interest, motivation). Calderhead points out additional criteria - for example innovation that is experimental or unestablished is likely to lead to resistance if there is little congruence with the teacher's ideological beliefs and values.

The process of translating beliefs into action is powerfully mediated by the context of teaching, including perceived and unperceived influences and constraints - external assessment and examinations; external control of curriculum; the need for approval from head, governors, parents, colleagues; school norms; classroom size; HMIs; school ethos; and so on. Calderhead's views on why educational research does not provide "ready solutions to classroom problems" echo those mentioned earlier: for example, each real world problem has a unique causal nexus, and a unique constellation of influences and constraints, and demands a variety of context-dependent responses; teachers "bring their own values and beliefs to teaching" which predispose them to particular strategies and pursuit of particular outcomes. "A more feasible and productive role for educational research is in providing the conceptual means by which teachers can reflect upon their own and others' teaching and consider how it can be changed and developed" ... educational research provides "a way of conceptualising teachers' practice, and revealing the kinds of knowledge that teachers have acquired, the interpretations they make of classroom events, and how these guide teachers' actions". Its value does not lie in providing prescriptions or recipes for action, but in promoting teachers' reflections on their practice, its development, how it is mediated by its working context, and how it influences the learning and attitudes of pupils.

Claxton (1990) discusses the importance of our images of the relationship between teacher and learner: e.g. believing we can 'give' knowledge implies a model of the teacher as a 'petrol pump attendant', and the child as passive recipient; the teacher who wants to 'fix' children's unscientific ideas is like a 'watchmaker', tinkering with the child's brain (and hence denying the child's active role in learning, and the essential requirement for a perceived need to know). More friendly images are that of the gardener, where the learner grows by taking in nourishment and converting it to its own fabric - the gardener assists but doesn't determine; and that of the 'sherpa', the knowledgeable guide to the explorer of unfamiliar terrain. Murphy (1997) echoes the importance of such images in shaping both teachers' individual and schools' collective mediation of curriculum, teaching load and assessment, arguing that such shaping

images will be counter-productive if they do not encapsulate the central role of ‘agency’ in learning, and promote sensitive management of ‘locus of control’ and ‘instructional density’.

Eisner (1984) warns of the danger of distancing research from practice: “The attraction of general notions and standardised methods increases as one moves farther and farther from the classroom ... We must, I believe, rely on the judgement of those who live with the students they serve.” Schwab (1964) contrasts substantive with syntactic knowledge, describing the syntactic knowledge of a discipline (part of what is referred to here, in relation to science, as ‘the nature of science’) as the important ideas and skills in the domain; knowing how new ideas are added and deficient ones dropped and by whom; and the rules and procedures of good scholarship and inquiry. “Every art has rules but knowledge of the rules does not make one an artist. Art arises as the knower of the rules learns to apply them appropriately to the particular case. Application, in turn, requires acute awareness of the particulars of that case and the ways in which the rule can be modified to fit the case without complete abrogation of the rule. In art, the form must be adapted to the matter. Hence the form must be communicated in ways which illuminate its possibilities for modification” (p265). Bishop and Denley (1997) stress the qualitative transformation of the personal subject knowledge of graduate scientists that occurs as they learn to teach science, and Solomon (1994) agrees that “what is special about the scientific knowledge of teachers is their professional reorganisation of it”, going on to argue that research designed to “explore that facet of knowing rather than initial misconceptions, would better match the nature of the subjects, their honour, self-image and sphere of work” (p17). This is fairly good description of what this project sets out to do, in relation to primary teachers’ understandings of the nature of science, and the purposes of teaching it in primary schools.

2.6 Summary

The following represents an attempt to produce ten main points from this review:

1. There do not seem to be any 'right answers' as to the nature and philosophy of science - only more or less consistent views within particular contexts and in relation to particular issues: so pluralism and unconsideredness are to be expected in any particular context, possibly in inverse proportion to the thought that has previously been devoted to such issues in that context. These contribute to the common threads seem to run through the views of the nature of science across the blurred boundary between philosophers and sociologists of science, and the public, secondary science teachers, secondary pupils, and primary teachers. These latter populations may fall into three main groups *vis-à-vis* science - those who reject it outright; those who are interested only in personally relevant factual information; and those who are genuinely curious as to why things are as they are: but the conformation of the groups may change from issue to issue, and on any one issue the groups are not necessarily homogenous in terms of their members' perceptions of the nature of science.
2. The relationship between teachers' views of the nature of science and the messages about science that come across in their teaching, is disputed: but it has been found to exist in some cases, and may be something that gets stronger with experience. For experienced secondary science teachers, subject and identity - the nature of the subject and the nature of the self - knowledge, beliefs and values, are intimately intertwined.
3. Teacher confidence is connected to many factors, of which objectively measured subject knowledge is one, and how the teacher feels about their knowledge, another. Hence attempts to measure deficits in subject knowledge may be counter-productive in terms of effectiveness of teaching.
4. Primary teachers have grown increasingly confident of their science teaching since the introduction of the National Curriculum: and their confidence seems well-founded, on the basis of local, national and international evidence.
5. Experienced primary teachers may be likely to hold views of the nature of science that are more in line with recent thinking amongst philosophers and sociologists of science, than are secondary science teachers.

6. Personal constructivism, based on the notion of conceptual change within an individual, has largely given way social constructivism, and to ideas with a more 'postmodern' flavour based on the primacy of discourse as the medium of mind and learning, and connectionist models of learning and epistemology. However despite such nods in the direction of a pluralist model of knowing, the 'single-valued' nature of the curriculum and pedagogy persists.
7. Teachers' thinking, knowledge, confidence and professional identity are created by and subject to such a subtle network of influences and interdependencies that any simple model cannot but be called into doubt. Complexity and theoretical pluralism must be anticipated.
8. Identity is created out of re-constructed life history. Identity, agency, beliefs and values are at the heart of personhood. A teacher's professional identity is founded on their personal identity, and in turn on lay theories created through their life experience. These understandings of identity provide a theoretical infrastructure for an autobiographical mode of enquiry.
9. Professional development seems to rest on reflective practice. It may involve a kind of evolutionary mechanism, as both reflection and practice provide opportunities for the generation and selective retention of new actions, ideas, values and connections; and is always embodied in a person with a life history, and thus could perhaps be seen as continuing development and recreation of professional identity.
10. Influential analyses of what teachers know and do have shaped much of the discourse of research in teaching and learning for many years. To some degree such programmes may have a reductionist flavour. To the extent that the objects of study are emergent phenomena, such programmes will be unable to achieve complete success. Other, more phenomenological approaches may make useful contributions.

3. The pilot study .. an exploration of seven teachers' perceptions of the nature of science and the purposes of primary science teaching

"They spoke long and eagerly .. they not only agreed to discuss; they seemed to be suffering from discussion starvation." (Solomon 1987 p73)

3.1 Research method

The main aims of the pilot study were to explore some individual teachers' perceptions of the nature of science and the purposes of primary science teaching, and by implication their self-images as science teachers; and to validate some methodological approaches. Following the observation by Goodson (1991) and others of the way in which teachers talking about curriculum development and subject teaching constantly import data about their own lives into the discussion, the study was designed around in-depth interviews which included a substantial element of reported life history (Bertaux, 1981; Goodson, 1983; Butt, 1984; Woods, 1993; Day, 1993) related to science- and education-related experience, as well as solicited views on the National Curriculum for science. The specific research questions addressed in the pilot were:

- what are the teachers' views of the nature of science?
- what do they see as the purposes of teaching science in primary schools?
- how do they understand and recognise progression?
- how do they see the primary science curriculum?

The sample of seven teachers had in common the regular teaching of science to primary classes. They were not randomly selected in order to be, in any statistical sense, representative of the whole English primary teacher force: rather they were purposively recruited to ensure that there was a mix of levels of experience, gender, ages of children

taught, science backgrounds, roles in school, and the types of school at which they taught.

All the interviews were carried out in Spring term 1996, to a schedule which was only loosely structured. Interviews began with a pre-amble touching on the purpose of the research, confidentiality, logistics, what the interview would cover, and an account of the interviewer's non-judgemental stance. Topics covered with every participant included the teachers' childhood experiences of home life and schooling, their further education and any employment other than teaching, their reflections on science and their own science teaching, and their views on the appropriateness of the science content in the *National Curriculum*. The teachers talked very readily, so the order in which the main topics were covered varied considerably. Discussions were open-ended, with minimal prompting. Two specific questions asked of every teacher in exactly the same words, were: whether they shared the *National Curriculum's* objectives for primary science; and whether there were ways in which primary science teaching could be improved.

Each interview lasted between one and two hours. Following transcription, the interviews were analysed by the author, and the analyses were spot-checked by a colleague. Teachers' views of the curriculum were subject to systemic network analysis (Bliss and Ogborn, 1979; Bliss et al., 1983; see *Methodology and Research Design* chapter for an extended discussion) to develop a category system that was both necessary and sufficient to accommodate all the views expressed, and to verify that all the teachers had covered the same ground. This demonstrated a consistently broad data-base, albeit with *idiosyncratic* additions, from which to study these teachers' views about science teaching.

Individuals' views were then reviewed in the context of the education- and science-related aspects of their life history, to give an idiographic account of the ways in which they make sense of the values and purposes that they bring to their science teaching and to their evaluation of the curriculum. Full details of the pilot project can be found in Lunn (1996) and Lunn and Solomon (forthcoming).

3.2 Main results and conclusions from pilot study

The pilot study suggested that at least some primary teachers are sufficiently comfortable with teaching science that they have well-warranted views on the content and operation of the curriculum; how their own practice could be improved; how practice in primary science in general could be improved; the purposes of teaching science in primary schools; the importance of the teacher's subject knowledge; the discussion of topical science issues in the classroom; and the nature of science and scientists.

Warrants for these views were found to be based on experiential knowledge from the classroom; pedagogic science knowledge; general pedagogic knowledge; collegial knowledge; and in the case of one teacher, theoretical educational knowledge.

The study suggested that some teachers have:

- 'secret gardens' of science content, beyond the curriculum, that they would like to (or do) teach
- a range of cognitive and pedagogic concerns about science teaching
- a range of strategies for coping with weaker areas of subject knowledge.

Having taken ownership of science teaching as part of their professional practice, at least some teachers feel restricted by the homogenised and limiting nature of the science curriculum, and their lack of autonomy in making curricular decisions in their own classroom. They express a positive desire for more freedom and time to pursue ideas that interest and excite their pupils.

The study also suggested that:

- teachers' perceptions of the nature of science are pluralistic and context-dependent: they cannot be placed in single simple position
- the teachers' science-related life histories are consistent with and mutually validating of their warrants for their views on the science curriculum

- the idiographic accounts provide indications of how science teaching has been accommodated into professional identities constructed around the teachers' life histories.

Some teachers seemed explicitly aware of a relationship between science teaching and identity or self-image - for example Florence explained that she had grown up in a family where science was important, so "it was already part of me": whereas Christine had "never felt comfortable with it", explaining that "it just isn't me".

Methodologically, the pilot validated the rather discursive and interactive approach to semi-structured interviewing, and the use of systemic grammar networks as research design and analysis tools. It suggested that teachers' biographies can be used to contextualise their views and the warrants used to substantiate them, and can shed light on how their professional identities are established. In terms of the transactions between researcher and participant, it showed that the experience of taking part in research that promotes reflection on practice can be of both professional and personal value to teachers. Finally it contributed a battery of teachers' statements and views that provided a valuable resource in the design and preparation of interview schedules and the survey instrument, in the main study.

As described above, the pilot aimed to explore individual teacher's perceptions of the nature of science and aspects of teaching it, with a suspicion that the context provided by their auto-biographies might be useful in understanding their views. What came through most strikingly from the data, was a clear indication of how their views of science and science teaching seemed to be constructed within this autobiographical framework, and to be intimately embedded within their professional identities and self-images: this was felt to be convincing enough to form the basis of the main study.

4. Research Questions

"What is special about the scientific knowledge of teachers is their professional reorganisation of it. Research designed to explore that facet of knowing rather than initial misconceptions, would better match the nature of the subjects, their honour, self-image and sphere of work." (Solomon 1994, p17)

4.1 Focus and rationale of research questions

The focus of this research is the relationship between the primary teacher and science.

This relationship is complex and multi-faceted: the facets attended to here are the teachers' views and their relationship with practice. In particular:

- the teachers' perceptions of the nature of science and science teaching;
- the teachers' reflections on their roles as science teachers;
- the teachers' education- and science-related auto-biographies;
- manifestations of the above in the planning and teaching of science units;
- the place of science and science teaching in the teachers' professional identities.

This focus, the fore-shadowed problems that shaped it, and the results of the pilot study, led to a number of problems and hypotheses, which are reproduced below just as they were formulated at the beginning of the main study, and which may be taken to represent the kind of thing I was expecting to find, and which may be compared with what I did find, as described in subsequent chapters:

- i) Primary teachers' understandings of the ontological status of science, its processes, explanations, models, relationships with other subjects, criteria of demarcation, knowledge claims, the way scientific knowledge changes, and its ethical, social and 'human' aspects may all affect their attitudes towards science and science teaching, and the images of science they communicate to their pupils. A primary aim of this work is to collect data on these areas and to explore their interconnections.

Individual teacher's understandings of the nature of science are expected to draw on a variety of sources of experience and philosophical traditions in an eclectic and context-dependent way. Realism in biology may give way to phenomenalism in physics. An empiricism derived from aspects of their classroom work is to be expected, alongside procedural knowledge and elements of, for example, the hypothetico-deductive position, the 'consensualist' view, varieties of realism, the 'no right answers' view of modern relativism, the 'one discourse amongst many' view of post-modernism.

- ii) As professionals in action, primary teachers might be expected to hold clear views of the purposes of primary education. One aspect of this research will be to describe how teachers' understandings of the nature of science are reflected in their view of the value of primary science education. It might be expected that this would include not only cognitive aspects, and familiarity with scientific knowledge and processes, but also social purposes such as informed citizenship (in as far as they consider young pupils able to understand such a concept, see Solomon 1993) and co-operative working; affective purposes such as inspiring an urge to look closer, and a love of understanding; relationships with other subjects such as Maths, Technology and topic work; and distinctions between the purposes of primary and secondary science.
- iii) Pressure to get good public results for the school, and their perceptions of the value of science, may have provoked reflection on the nature of progression in science. Three areas of knowledge are expected to provide warrants for teachers' views on progression - knowledge of primary education in general, of children, and of science itself.
- iv) It will be important to probe how far the teachers' own understandings are in agreement with statements in the National Curriculum and the practice it promotes. Any conflict in this area might be expected to impinge on their practice.

- v) It is expected that teachers' understandings and perceptions will be affected by their backgrounds in science in terms of education, formative experiences, in-service training, interests, and social and professional contacts. These connections will be carefully explored.
- vi) It is expected that the teachers' classroom presentations of science will be affected by their views of science, causing them to deliver implicit or explicit messages on the nature of science and the purposes of learning science: and that this relationship will be reflexive, i.e. that their experiences of presenting science in the classroom will effect their views of the nature of science. This will also be carefully explored.
- vii) It is expected that teachers will vary in their perceptions and professional practices, and that these variations may be related, e.g. to the extent that a teacher sees science as a body of knowledge, they may see the purposes of primary science as building up pupils' science knowledge, and progress in terms of accumulated facts; whereas a teacher who sees science as a way of finding out may see purposes in terms of problem-solving, experimental design and discovery, and look for progress in terms of the cultivation of disciplined curiosity or asking good questions.
- viii) It is expected that teachers' reflections on the nature of science, that may be stimulated by issues raised during interviews, may lead to changes in the views of science accessible to their reflection, or implicit in the planning or presentation of a science unit.

In so far as it is valid to summarise these concerns into a few lines, the questions that this project set out to answer are:

- Q1. How do primary teachers perceive their personal experiences of science; their personal experiences of science education; the nature of science; primary science education; and themselves as primary science teachers?
- Q2. What views of the nature of science and of science education are manifest in primary teachers' approaches to planning and teaching a science unit or topic? Do such views appear to change or develop following in-depth discussion of these subjects?

- Q3. What kinds of warrants are offered in support of their views? Do they give any indications of the ontogeny of their views; of the kinds of knowledge being deployed; of the stance from which the view is being offered (having implications for identity)?
- Q4. Is it possible to describe the nature of professional identity in these teachers, and how science teaching is accommodated into it?

4.2 Evaluation of research questions

This section evaluates the research questions in terms of criteria defined by McIntyre (1995), whose requirements of a good research question are:

- clarity;
- that it is empirically answerable;
- that assumptions and implicit values are made explicit;
- that it stands in some well-defined relation to previous research - either building on it, replicating it with some variation e.g. geographical, re-conceptualising an area, or opening up a new field - and to previously developed theory - building on or within or critically questioning a theoretical position, or developing 'grounded theory';
- that evidence is accessible in principle and in practice;
- that the political positioning and implications have been considered;
- that the question is practically manageable for the researcher;
- that the question has significance and practical usefulness, i.e. that it contributes to theory or has implications for policy or practice.

It is argued that the above questions meet these criteria reasonably well.

The language is unambiguous, and is not embedded in an ideological tradition - it would be expected that researcher and participants in the research should be able to reach a common understanding of what the questions mean with little difficulty. The questions

do not contain any noticeably emotive or value-laden words, and for the most part they relate to observable phenomena, discourse, and participants' experiences of and reflections on them. The exception to this latter is the reference to professional identity in Q4 - this is a hypothetical or theoretical entity, whose use in an empirical enquiry is legitimate because exploration and description of its nature and its authenticity are implicit in the question.

The questions are empirical in that the only way to answer them is to collect evidence, and are fairly free of contentious assumptions and implicit values - perhaps the most important assumptions implicit in the questions are:

- that primary teachers do have views of the nature of science: in fact the ontological status of their views, their stability, coherence and 'consideredness', are issues of interest in their own right;
- that teachers have or develop professional identities - again an issue of interest.

The questions' relation to previous research is, in essence, that they build on previous theory and research in several areas, and seek a measure of integration. The theoretical base is a family of ideas around agency, identity and social action, drawing on the work of Rom Harré, Anthony Giddens, and Charles Taylor. Related research includes work on:

- the understandings of the nature of science held by various groups, e.g. science teachers, students, members of the public, and a relatively small amount of prior research on the understandings of primary teachers;
- extensive work on teacher knowledge and thinking;
- relationships between teachers' beliefs, biographies, professional identities, and practice.

Evidence as to the nature of primary teachers' views is accessible in principle and in practice; and the pilot study suggested that a combination of life history elicitation and in-

depth interviews around areas of intense professional interest makes aspects of professional identity accessible.

The questions' political stance is intended to be neutral in ideological terms, though democratic in that it seeks to help give a voice to and to be in sympathy with the perspective of 'reflective practitioners', who seek to understand and improve their own conceptualisations and practice.

The project was planned so as to be manageable in practice, in terms of time, access, characteristics of the researcher, etc. It is argued that it is worthwhile in that it explores an area that we need to understand better; that it may contribute to our theoretical understanding of teaching and teachers; and that it may have implications for policy and practice, for example in relation to the development of the primary science curriculum, pre- and in-service education and training, and the role of subject specialists in primary schools.

5. Methodology and research design

5.1 Introduction

The methods used to gather and analyse data are determined by the research questions being asked, and by the nature of the answers sought. Both questions and methods tend to be categorised into two main groups - quantitative and qualitative - often related to how well understood the objects of enquiry are. Cronbach (1982, p74-5) argues for a predominantly qualitative approach: "the more the observer learns of detail and process, the better; observation from afar is impoverished. The impersonal, pre-designed research study is of little use in gaining a new idea .. however useful it may be in confirmatory research or in routine monitoring." All social science, in his view, is case study.

Quantitative questions tend to relate to already well-understood, readily categorisable and countable aspects of behaviour or experience. Their data gathering techniques include surveys, questionnaires, structured interviews and systematic observation (e.g. Bennett 1976, Galton et al 1980). Questions asked tend to be relatively simple and 'closed'; and observation schedules tend to specify straightforward and as far as possible unambiguous categories. These methods can access 'surface features' of attainment, attitudes, opinions, biographies, etc., from large numbers of people; can show correlations between such variables; and can be used to test hypotheses generated from theoretical explanations, or to give estimates of the distribution of attitudes or beliefs in the general population: but are inappropriate for exploring deeper phenomena, whose variables cannot be exhaustively pre-defined, such as a teacher's ambivalence towards some externally imposed change.

Qualitative questions relate to relatively unexplored or inaccessible 'deep' features, often of a cognitive, phenomenological or cultural nature. In the educational context we may be trying to get at the deep structure, integration and development of subject and pedagogic knowledge, conceptualisations of teaching and learning, or meta-cognitive processes such as reflection in action (e.g. Shulman, 1986; Calderhead, 1988; Schön, 1983). We

may be doing this ‘on-line’, when the thinking we are trying to access is actually being employed; or ‘off-line’, when someone is talking about what they do but not at that moment doing it: and we may be focusing on their pre-active thinking, for example their planning, or their inter-active thinking, that which takes place during teaching. This gives four possible combinations - examples of the kinds of method that may be appropriate for each are:

	off-line	on-line
pre-active	semi-structured interview	protocol analysis
inter-active	stimulated recall	observation

Talking with people ‘*off-line*’, about their views, experiences, perspectives, thinking, lives, or lesson planning might involve semi-structured or unstructured interviews (Measor 1985); recollections of what they were thinking when they behaved in a certain way when teaching, their ‘thinking in action’, might be stimulated by questioning them while they watch a video-tape of episodes in a lesson (Calderhead 1981). Access to teachers’ thoughts during lesson planning might be gained by ‘protocol analysis’ (de Groot, 1965; Peterson and Clark, 1978; Ericsson and Simon, 1993); and various kinds of observation may yield data about interactive behaviour of teachers in action.

Observation methods vary in duration, degree of pre-defined structure in the observer’s focus, and degree of participation by the observer, on a spectrum from uninvolved observation (e.g. King 1984, 1989), to participant observation or ethnography (e.g. Lacey 1970).

The great strengths of the quantitative approach are its susceptibility to statistical analysis and hence, given appropriate sampling, the generalisability of its findings, and the fact that the findings are expressible in relatively simple and generic terms, with known confidence limits. These can also be seen as its great weaknesses, since reducing human cultural and psychological phenomena to a limited set of categories involves simplification and loss of context at both in data gathering and statistical analysis. Guba and Lincoln (1981) argue that since all human behaviour is mediated by context, context-

free generalisations tell us little that is useful about human behaviour: Geertz (1993b, p129-130) maintains that they are either “so general as to be without intellectual force or interest”; or they are “ill-based”. Thus there appears to be an unbridgeable gulf between the quantitative tradition, where control of variables, replicability and generalisability are the *sine qua non* of social research (e.g. Campbell and Stanley, 1963; Krathwohl, 1985); and the qualitative tradition, where rich contextualisation and thick description of individual cases enable interpretation and perhaps comparison, but make control of variables and replicability impossible, and where generalisability is seen as neither a useful nor an attainable goal (e.g. Geertz, 1973; Cronbach, 1982; Goetz and LeCompte, 1984).

Various attempts to reconcile these traditions have been made over the last thirty years - for example the rehabilitation of case study research in the later work of Campbell (Campbell 1979); multi-site studies (e.g. Firestone and Herriott, 1984); meta-studies synthesising multiple earlier qualitative studies (e.g. Yin and Heald, 1975; Noblit and Hare, 1988); and development of new conceptions of generalisability which are more useful in qualitative work, for example Guba and Lincoln's (1981, 1982) concept of 'fittingness', Goetz and LeCompte's 'comparability' and 'translatability', Schofield's (1989) qualification of these in terms of the relationship between site selection and whether the 'target' of generalisation in these senses is 'what is', 'what may be', or 'what could be', and Elliott's (1990) argument that the external validity of case studies rests on their “usefulness as projective models”, helping others “throw new light” on their own situations..

In this research the focus is on 'what is'. The pilot study explored the question 'How do primary teachers perceive the nature of science and the purposes of teaching it?', using the purely qualitative method of semi-structured interviews. It showed that teachers' perceptions were complex, pluralistic, and influenced by context: and generated a hypothesis as to the existence and ontogeny of a 'professional identity' into which teachers had accommodated science teaching in a variety of ways.

The objects of interest in the research questions of the main study are again primary teachers' perceptions of science and science teaching, and also the warrants they give for their views, and their reflections, life histories, lesson planning, and science teaching - all of interest in their own right, but also serving the purpose of the final question - 'Is it possible to describe the nature of professional identity in primary teachers, and how science teaching is accommodated into it?'.

Clearly some aspects of these objects of interest are in some degree 'categorisable and countable', and so are amenable to quantitative methods - other aspects, especially those contributing to the exploration of professional identity, demand a deep study of individuals as whole persons, over time, from several distinct perspectives.

Thus a substantial qualitative part of the main study must be

- 'particularistic' in portraying a limited number of individuals' situations;
- holistic in trying to capture a picture of the teacher as a whole person, including historical and contextual data as well as various aspects of, and their reflections on, their practice;
- longitudinal, in acknowledging the possibility of and looking for change over time.

These parts of the study thus satisfy Wilson's (1979) 'generic qualities' of case studies - and will require and provide a 'thick description' (Geertz 1973) of each case.

In the world at large, qualitative research suffers for its context-specificity, which precludes generalisability, and for its rich descriptions, which make it difficult to produce pithy and accessible 'bottom lines'. Often both policy-makers and those with a background in the natural sciences find it hard to understand many social scientists' preoccupation with understanding social processes through case studies, ethnography, or qualitative work in general: there is a hunger for generalisation and, in educational research in particular, for results with immediate application in the classroom (e.g. Clarke, 1998; DfEE, 1998a).

On the other hand qualitative work arose, at least in part, from concerns about the adequacy and internal validity of categories and constructs in quantitative research - the authenticity of personality traits and attitudes, the need to understand social process and praxis, the effects of context and the situated nature of cognition (e.g. Blumer, 1969; Lacey, 1970; Keddie, 1971).

The research design presented here includes both quantitative and qualitative strands, represented by a survey and five case studies of individual teachers ('case study' is used here in the 'psychological' sense of a focus on an individual person, rather than the 'sociological' sense of focus on a particular setting, group or institution). Each strand constitutes an attempt to produce a valid and useful piece of research in its own right, within its own tradition; *in combination* the two go some way towards addressing the paradigmatic weaknesses of qualitative and quantitative work - i.e. generalisability and internal validity respectively.

They do this in the following way:

1. The semi-structured interview data and analysis results from the pilot study help identify those aspects of teachers' life histories and perceptions of science, science education and teaching that are amenable to quantitative investigation; and provide a sound foundation for the development of a survey instrument to address those aspects. As Elliott (1990) argues, identification of the range of views in a population by unstructured or semi-structured interviews with multiple respondents, though it can never be exhaustive, can form the basis for identifying categories of response, whose distribution in the population can be determined by survey.
2. The case study teachers, as well as being intensively interviewed and observed, also completed the survey questionnaires.
3. Comparison of case study teachers' answers to the questionnaire, with their views discursively expressed and explored in interview, and their professional actions in planning and teaching, enable the internal reliability of the survey to be assessed, by

exploring the extent to which each survey answer is confirmed, supplemented, and/or contradicted, in each set of case study data.

4. Given that the internal reliability and validity of the survey is established, and that the sample can be taken to be representative of the wider population of primary teachers, we can address the external validity of the case studies by locating each case study teachers' survey responses within the frequency distributions for the sample as a whole, thus demonstrating clearly their typicality or otherwise across the whole range of issues covered by the survey.

Thus the research design for the main study is based on a small number of case studies which run in parallel with each other, and with a survey of a larger group of primary teachers *which includes the case study teachers* and which thus creates the mutual reinforcement of reliability and validity inherent in the research design.

The following sections discuss some of the implications for the design of researching professional practitioners; ethical issues; access to and relationships with case study participants; reliability and validity; the overall research plan; and the design and execution of the survey. Some notes on the use of Systemic Grammar Networks are included in the discussion of reliability and validity - this is a modelling tool which was used extensively in the development of interview schedules and survey questions, and in the analysis of interview and other case study data, in both pilot and main studies.

5.2 Implications of researching professional practitioners

Teachers put their ideas, knowledge, and beliefs into practice when they perform the actions that constitute their professional activities. Agyris and Schön (1974) argue that there is a difference between situated action and decontextualised comment, between 'theory-in-use' and 'espoused theory', and that we cannot gain access to someone's 'theory-in-use' just by asking them questions - we need to observe them in practice in order to reconstruct it. Others would argue that the tacit nature of much professional thinking means that authentic accounts of practitioner thinking require the grounding of

discussions in practice; that discussion of this practice would enable the practitioner to contribute to the reconstruction of their 'theory-in-use'; and that research so grounded is most likely to generate findings that are of relevance and value to practitioners (e.g. Connelly and Clandinin, 1984, 1985; Brown and McIntyre, 1993; Cooper and McIntyre, 1996). Most research in which practice is privileged in this way begins with the observation of the teaching and learning events of some lesson or lessons, and then works through these by talking to the teacher about their thinking and experiences in the lesson, in some cases using video recording and 'stimulated recall'. It is possible to see 'protocol analysis' as a parallel technique for use in situations where the professional practice involves actions in which the practitioner does not interact with others, such as lesson planning (Hart, 1996; Calderhead, 1981). Notwithstanding Bromme's (1984) arguments against the use of the 'theory' metaphor (based on a rather formally defined notion of theory) in the study of teachers' knowledge, the idea of 'personal theory' is used here, with a distinction being drawn between such theory espoused in interview, and what is inferred to lie behind teachers' actions and words in planning and in teaching - theory-in-use.

Teaching is an intensely personal activity: the professional actions discussed above are mediated by teachers' identities, and take place in the context of their life histories, so that, as Goodson (1992b, p234) suggests, in order to understand what they are doing, "it is critical we know the person the teacher is". Goodson (1992c) distinguishes the teacher's own 'life story' from a collaboratively constructed and more broadly contextualised 'life history', while arguing strongly for the priority of 'the teacher's voice' in educational research. Giddens (1991, p80) emphasises the centrality of a person's life story in their construction of self -

"development of the self is *internally referential*: the only significant connecting thread is the life trajectory as such. Personal integrity, as the achievement of an authentic self, comes from integrating life experiences within the narrative of self development: the creation of a personal belief system.. key reference points are set 'from the inside', in terms of how the individual constructs/reconstructs his life history."

Harré (1998, p135) describes the self as partly constituted by

“the beliefs a person holds as to their own nature.. offered to oneself and/or others, at some moment in one’s life... [but] my self-concept, that is my beliefs about my [self], may not accurately reflect it... What then is an autobiography? One might say ‘the story of a life as told by the person whose life it is’. A little reflection shows that this common-sense definition is simplistic. For a start one has to acknowledge that there are many stories that one could tell about one’s life. Which one reveals the ‘real me’? Postmodernists would answer ‘None - there is no real me’. I would answer ‘All - each reveals an aspect of what I am’.”

Together, these strands suggest that attempts to understand the thinking of individual teachers must be rooted in their practice, *and* set in the context of their life histories and professional self-images.

5.3 Ethical issues: responsibilities to participants, funders, and the research community

This section draws on a number of published codes of practice and guidelines - BERA (1992), BPS (1990), BSA (1993), Open University (1998) - and on Foster (1999) and Hammersley (1991, 1995).

As in any project demanding the time of already over-stretched teachers, the fundamental ethical challenges here are to make sure that the project as a whole justifies the personal investments of time and emotional commitment that the participants put into it; and that for each of them, the effect of their involvement is of net benefit or neutral, and not harmful. The goals of the project must be worth pursuing in terms of the furtherance of knowledge, and the conduct of the project must be appropriate for achieving those goals. These challenges underlie the researcher’s responsibilities to participants, funders, and other educational researchers, which are elaborated below.

Responsibilities to participants apply in all types of research, but vary in degree with the nature of the participant’s involvement - for example the written account of the research included in the covering letter sent out with the questionnaire was compatible with but

less extensive than the face-to-face explanation given to case study participants who were going to spend many hours being interviewed and observed, and gatekeepers who controlled access to them. Responsibilities to participants include:

1. Not deceiving them (by commission or omission), but giving them as full an account of the research as they want or will accept, and ensuring that they clearly understand how the data will be used and the nature of the anonymity, privacy and confidentiality that can be guaranteed; and gaining their 'informed consent' at the outset, and in the case of long-term involvement, verifying it at intervals during the project. As far as possible, this was fulfilled during telephone and face-to-face conversations during their recruitment to the project; confirmed in writing once they had signed up, by way of a 'briefing pack' that was sent to each; and verified at intervals during the project by asking for their reflections on their experience, and whether they had any problems with taking part. In the event two of the seven teachers who were initially involved withdrew after one and three sessions respectively.
2. Maintaining anonymity, privacy and confidentiality (while minimising loss of data and context); taking steps to ensure that they are maintained by everyone with access to the data; and respecting the privacy of anything learned about participants beyond what they have agreed to offer to the project, and of anything learned about others incidentally involved, for example children in observed classes. This was achieved by changing participants' names, school names, and any other potentially identifying data, on all documents relating to the project including tape transcripts and tape labels, and keeping the tapes in a secure place; by not communicating real identities to anyone, except in one unavoidable case, to my supervisor, who has guaranteed to maintain security; and by selective transcription of remarks that go beyond the agreed ambit of the project.
3. Ensuring as equitable a balance as possible in the power relationships between researcher and participant, and between what each party brings to and takes from the project; and being prepared to discuss any concerns and answer any questions that participants may have, in so far doing so does not invalidate the research process.

4. Minimising negative effects on participants' self-esteem or professional self-image, that may arise from asking difficult and challenging questions that lead to hard thinking and reflection; offering participants the opportunity to amend, withdraw or add commentary to what they have said or the data they have contributed; and ensuring that they understand the voluntary nature of participation, and their right to withdraw should they feel they cannot continue for any reason.
5. Trying to ensure that the research does not disturb the relationships between participants and any 'gatekeepers' who have been involved in gaining access to them; that there is no unnecessary interference with participants' professional activities; and that no adverse personal consequences flow from participation, making it a positively beneficial experience as far as possible.

The research is funded by an Open University studentship. It must be and has been conducted in an ethically responsible and effective way, that attempted to enhance the Open University's reputation among those who come into contact with it.

Though absolute truth and objectivity may be unattainable in principle, rigorous and transparent efforts to pursue and approach them, and to produce accounts that represent the phenomena under study as accurately as possible, are part of the duty the researcher owes the research community. Clearly neither data nor lack of data can be fabricated or concealed; but also data collection, analysis and interpretation must be systematically designed, conducted and checked to minimise and identify error and bias in evidence and findings; disconfirming as well as confirming evidence should be actively sought; and the research process and all its products should be open to critical scrutiny. This chapter describes the range of methodological attempts made to meet these criteria: work-in-progress and results have been shared with and exposed to the critical comment of colleagues at a series of conferences and workshops both within and outside the Open University (e.g. Open University Research Seminars, 1998-1999; various presentations to and discussions in 'Dipsy', an Open University graduate students' discussion group in discursive psychology, 1998-2000; ESERA's 4th European Science Education Summer School, Paris 1998; the BERA Advanced Research Training workshop, Bristol

1999; the 18th International Human Sciences Research Conference, Sheffield 1999; the Ethnography and Education Conference, Oxford 1999).

5.4 Access to and relationships with case study participants

Both the literature (e.g. Measor and Sikes, 1992; Ulichny and Schoener, 1996), and experiences during the pilot project, made clear the centrality of the relationship between participant and researcher in long-term qualitative research; and hence its influence on the quality of the data produced, and the quality of the experience of taking part, for all involved. An open, honest, democratic relationship, that both parties feel they can shape, enjoy, and gain from, was pursued as best meeting these twin goals of quality of data and quality of experience. Too democratic an approach to negotiation of roles could have threatened reliability and validity by introducing idiosyncratic contexts and reducing comparability of cases, but in practice this did not seem to be a danger, probably because the contacts were researcher-initiated and it seemed appropriate to participants to let the researcher take the lead in jointly shaping the developing relationships and respective positions.

With case studies, selection of cases is clearly of great importance, and is influenced by the ambitions of the research - in Schofield's (1989) terms, whether the 'target' of generalisation is to be 'comparability' or 'fittingness' with 'what is', 'what may be', or 'what could be'. In this case a focus on 'what is' implies purposive selection of 'the typical, the common, the ordinary', and the necessity of steps to demonstrate that selected cases are indeed so; and of examples amongst participants of each of the main variants in the background variables that may be pertinent, for example males and females, with different levels of experience, teaching different ages of children, in different types of school. That said, we are rarely free to go out and choose our ideal combinations of people and settings, nor to study enough cases to cover all possible combinations of even such a short list of background variables. For an ethnographic study it may be a case of working with the single case to which we have access (e.g. Pollard, 1985); in any study involving a significant contribution of time from busy

teachers, participants are likely to be partly self-selected, and partly recruited through an iterative process of pursuing personal and professional contacts, and persuasion. Access may be direct, or via ‘gatekeepers’ such as head teachers - either way it has been found helpful to have some kind of *quid pro quo* that can be offered to the individual or the school to make the teacher’s participation in and contribution of time to the research a more equable transaction. Details of teachers recruited as case study participants are as follows:

	How contacted	Years exp.	Type of school	Ages taught	Quid pro quo
Andrew	Directly: head not involved: recommended by children of friends, who had enjoyed his science lessons: in both pilot and main study	20+	Middle, relatively affluent suburb	Y5	—
Howard	Direct contact, confirmed with head: I had worked in the school and knew Howard slightly; and knew the head as a fellow research student	20+	Primary (Infants and Junior), one of four in a large ‘dormitory’ village	Y3, Y5	Helped automate the school library and resource centre.
Jenny	-ditto-	5-6	-ditto-	R/Y1	-ditto-
Irene	Via head, whom I knew from having worked in the school, and who asked for volunteers from staff	3-4	Inner city Middle	Y6	I.T. training for teachers and LSAs
Keith	-ditto-	2-3	-ditto-	Y6	-ditto-
Linda	Approached Linda directly, at suggestion of an academic contact; then confirmed with head	4-5	Primary (Infants and Junior) in a rural village	R/Y1, Y3/4	Co-opted into Linda’s personal CPD programme
Marsha	Approached head via academic contact: Marsha ‘volunteered’	1-2	Inner City First School	Y3	—

As mentioned earlier, Marsha and Jenny dropped out after the first and third sessions respectively.

The case for reducing the asymmetry of the researcher-participant relationship by a certain amount of 'self-disclosure' on the part of the researcher (e.g. Oakley, 1981; Bertaux, 1981) was reinforced by experiences on the pilot study. Sharing a true account of the purposes and means of the research is to be favoured for both ethical and practical reasons - participants are treated with the respect that is their moral due; it is unreasonable to expect people from whom you conceal your truth, not to conceal their truth from you; and it is much easier to present a consistent account through long hours of conversations, if it involves no dissembling or deception. Equally, conversation in interview can flow more freely if both parties make substantive contributions, though the researcher's contributions have to be carefully constructed to avoid putting ideas into the participant's mind. In the pilot and main studies this was attempted by echoing anecdotes in an 'Oh, something like that happened to me, too' kind of way, or re-expressing/paraphrasing what the participant was understood to have said, to see if they still agreed with it, and/or made further distinctions, as well as making the conversational trade more equitable.

All interviews and observations were tape-recorded, and participants' comments about the recorder were noted. As Caronia (1999) points out, the recorder in a sense defines the situation - "taken out from the vanishing nature of lived action and conversation, the discourse is intentionally produced to become a permanent text fixed by the recording tool". All participants were made aware that they could go 'off the record' whenever they wanted, or choose not to discuss particular issues, or indeed drop out of the project all together - but in fact they seemed to share my concern that the tape recorder was functioning properly, and their words were being recorded, on occasion reminding me to check. Reflective discussion of the experience of taking part in the project showed that an awareness of being recorded never completely left them, and that to some extent and on some issues they felt they were speaking 'on the record' and on behalf of both themselves and their peers. Only on one occasion did a participant ask for the recorder to

be switched off, to go 'off the record' - Howard, in order to talk about performance-related pay.

Evidence of mistrust of the researcher's motives, account of the research, discretion, and ability to maintain anonymity, was very limited: it only occurred in relation to one participant, Howard, who on a small number of occasions appeared to suspect the operation of a hidden agenda. An open, candid approach, on the basis of which trusting and friendly relationships could develop, seemed to be the best means of countering this problem, together with consistent delivery on all arrangements and undertakings.

The end of the field-work for the project was a potentially difficult time. Long-term involvement, over a period of around eighteen months (or in Andrew's case some five years), in relationships that involve deep reflection and revelation of one's 'innermost thoughts', can lead to strong friendships: however there is a danger in the asymmetry of the such relationships, which the researcher needs desperately to keep going while the research goes on, but whose attitude is bound to change when it ends. Participants may welcome the end of data gathering as the end of their involvement, and by the time any analysis results or reports are available, may have lost interest, forgotten, or moved on; or they may feel they have formed a friendship that they would like to endure, or regret the passing of something that has become part of their lives. Each participant is likely to feel differently, and each merits being treated with care and sensitivity, for ethical and professional as well as personal reasons (Measor and Sikes, 1992; Hammersley and Atkinson, 1995). In this project, active contact has been maintained with two of the four participants who saw out the project and who are still in teaching, Andrew and Linda, instigated by them. Howard seemed pleased that his involvement was over; and although I have not been in touch with Irene since our last session, other than to send her thanks, transcripts, and copies of some of the reports that have come out of the project, we parted with warmth, and would, I feel sure, both be glad to work together again.

5.5 Reliability and validity

The following explores briefly the meanings of and threats to reliability and validity in the quantitative and qualitative strands of the study, and overall. For extended discussion of the issues see for example LeCompte and Goetz's (1982) systematic attempt to produce an understanding that is coherent and consistent across quantitative and qualitative contexts; Brown and McIntyre (1993) and Schofield (1989) on external validity or generalisation; Foddy (1993) and Strauss and Corbin (1990) on internal validity, which they refer to as 'matching meanings' and 'validation' respectively; and Hammersley (1991) and Hammersley and Atkinson (1995) for a balanced and realistic overview.

Validity is concerned with the accuracy of findings: reliability with their replicability. Each has what LeCompte and Goetz describe as 'internal' and 'external' aspects; and each has application in and implications for the research design, data gathering and data analysis phases of both qualitative and quantitative research.

For example in semi-structured interviews, validity and reliability come partly from the preparation for and conduct of the interviews, and partly from the analysis and interpretation of the data. Reliability corresponds to replicability in the natural science context, and is generally taken to refer to whether other researchers would produce the 'same' findings if they were to do the 'same' thing, i.e. if they asked the same questions, would they get the same answers; if they analysed the same data, would they come to the same conclusions (external reliability)? Or, given the data and the results of analysis, would others match the two together in the same way (internal reliability)? Validity refers to whether findings are 'real' or (to use a less philosophically loaded term) 'authentic'. Internal validity consists in the correspondence of findings to phenomena in the minds of the participants (rather than their being imagined/created/imposed by the researcher through bias or systematic error) and in their genuinely addressing the issues raised in the questions they purport to answer. External validity consists in their applicability in contexts other than that in which the research was conducted.

Threats to reliability and validity, and means of dealing with them, vary between research contexts. The following sections look at how threats from bias, misunderstanding, reflexivity, and skewed sampling, were countered in this project; and some general methods of promoting reliability and validity - triangulation, use of systemic grammar networks, verification by independent researchers, and certain personal qualities of the researcher.

5.5.1 Threats to reliability and validity

5.5.1.1 Bias

Researcher bias could have effects throughout the project, on the framing of the research questions themselves, the design of interview schedules, questions and prompts, the conduct of interviews or the aspects of classroom reality attended to in observed lessons, and the analysis and interpretation of data, and thus threatens internal reliability and internal validity. The main means of countering and controlling researcher bias employed in this project were:

- openness about the nature of that bias, from the inception of the project - hence the list of ‘problems and hypotheses’ created at the start of the main study and included above in the ‘Research Questions’ chapter;
- critical evaluation of each of the researcher's productions (e.g. interview schedules, interview transcripts, results of analyses, conclusions) by the researcher and, preferably, someone of different bias, with a view to identifying, noting and if necessary revising or re-visiting any dubious aspects - this ‘critical friend’ role was filled at various times by my supervisor, my wife, and my fellow research students;
- ‘respondent verification’ of the accuracy of transcripts and observation notes.

‘Respondent validation’ of findings and interpretation was considered but not implemented, though the findings from the survey were given to the case study participants and survey respondents after the case study data collection was complete: though feedback was invited, none was received, beyond a few ‘mm... very interesting’

comments. Lincoln and Guba (1985) argue that participants' acceptance of an account is essential to ascribing validity to it: Ball (1984) disagrees, arguing that the researcher's and participants positions, perspectives, theoretical repertoires and interests are different, and that we should not expect them to agree. Hammersley and Atkinson (1995) conclude that participants' reactions, whether positive or negative, "cannot be taken as direct validation or refutation of the observer's inferences", but instead can serve as "another valuable source of data" (p230): in this case the opportunity to collect this additional data was not taken, more for logistical than for methodological reasons.

5.5.1.2 Misunderstanding

During an interview, failure by a researcher to indicate how they define the research situation will lead to the respondent searching for clues and making guesses about the researcher's purposes, to help interpret what is being asked of them and decide what information they should give. If each participant does this in their own way, each may end up construing and answering what is effectively a different question, destroying the comparability of answers and the validity of any conclusions: hence the importance of the interview pre-amble or discussion of the research, in which a shared definition of the situation is negotiated (Foddy 1993); and of the on-going verification and re-negotiation of that shared understanding as the project progresses.

Misunderstanding of the researcher's questions and explanations by the interviewees, or of the interviewees' responses and explanations by the researcher, would clearly invalidate the research: it is important to internal reliability and validity that questions used in the interviews are framed in such a way as to be accessible to the participants and to achieve common meanings; and that the researcher understands the survey participants' responses. Internal validity in particular depends on 'matching meanings' between researcher and interviewee: thus the researcher's is a very active role involving making sure that the interviewee has understood each question as intended by the researcher, and has answered it to the extent that they feel able to; and that the researcher has understood the response as intended by the interviewee - a completely different

process from asking a closed question and ticking a box on a structured interview schedule. Careful preparation and openness, giving participants access to the research protocol and transcripts, are also counters to this threat.

5.5.1.3 Reflexivity

Researchers are part of the social world they study. They make social actions, engage in discourse, and influence the unfolding of that world, which in turn influences them and their perceptions and self-referential descriptions of it. Reflexivity refers to this interconnectedness, and implies that all data-gathering involves theoretical pre-suppositions and changes the situation about which data are being gathered: it is impossible to “isolate a body of data uncontaminated by the researcher”, neither by positivism’s ‘automaton implementing a standardised research procedure’, nor by ethnography’s ‘neutral vessel of cultural experience’ (Hammersley and Atkinson 1995). This problem is endemic through all social research, and there are no ‘magic bullets’: strategies adopted in this project include maintaining realistic expectations in regard to the impossibility of absolute security and certainty of knowledge; triangulation, especially between techniques where the researcher’s influence differs significantly; and reflective commentary from participants, and discussion between participants and researcher, on their experiences of engaging in the research process.

5.5.1.4 Skewed Sampling

‘External’ validity is required to yield results of any meaning and value outside the context in which they were collected. In quantitative work this arises from the size and representativeness of the sample, which underpin confidence estimates in statistical tests: too small a sample will be more likely to be skewed by chance, and a large sample that is not randomly selected will be unrepresentative and hence unable to support statistical generalisation. The size of sample required for a given level of confidence depends on the nature of the statistical test and the variables in question - for example, factor analysis requires factor loadings of >0.7 with a sample size of 60, for significance at the $p<.05$ level (Hair et al., 1995) - so the sample size achieved in the survey in this project, of 61

full-time class teachers, was just enough to support this test at this level of confidence. In qualitative work external validity normally depends on purposive selection of cases that are appropriate to the purposes of the research, and on rich description and contextualisation enabling comparability between this and other contexts where the findings may have relevance (Geertz, 1973; Denzin, 1983; Schofield, 1989). Additionally a kind of triangulation between quantitative and qualitative results is used here to demonstrate the *typicality* of the case study teachers, adding to the external validity of the research as a whole, as described below.

5.5.2 General methods of promoting reliability and validity

5.5.2.1 Triangulation

Perhaps the most important guarantee of internal validity across the project as a whole is 'triangulation', a technique loosely based on an analogy with land surveying and navigation. Trying to fix one's position on a map, one can take a bearing on some known point, draw that line on the map, and know that one is somewhere along or close to that line, with unknown error. Bearings on two known points will give intersecting lines on the map, and one knows one is somewhere near the intersection, but still the error in the bearings is unknown. Bearings on three known points normally fail to intersect at a single point, but to result in a triangle, known to navigators as a 'cocked hat', the size of which gives an indication of the degree of error in the bearings. Hammersley and Atkinson (1995) suggest that the key role of triangulation is not to check the truth or validity of the data, but to investigate the validity of inferences drawn from them, in what they describe as 'reflexive triangulation'; and describe three variants of triangulation:

- data-source triangulation: using data relating to the same phenomenon but derived from different sources - different phases of the investigation, different points in temporal cycles, different participants
- researcher triangulation: using multiple-researcher teams to provide multiple perspectives on the same phenomenon

- technique triangulation: comparing data produced by different data gathering techniques: “to the extent that these techniques involve different kinds of validity threat, they provide a basis for checking interpretations” (p231).

Types of triangulation are built into the research design here at two levels: within each case study, and between case studies and survey.

Within each case study, data on the teacher’s experiences of and reflections on science and science teaching are gathered by a variety of techniques over an eighteen-month period:

- protocol analysis and reflective discussions on the planning of a science unit or series of science lessons
- observations of science lessons
- semi-structured interviews and reflective discussions on the teacher’s life history, especially in relation to science outside school and in their own education, and their own training and professional development
- semi-structured interviews and reflective discussions on the nature of science, its relationship with morality, and its importance for ordinary people
- semi-structured interviews and reflective discussions on teaching in general - models, metaphors, theories
- semi-structured interviews and reflective discussions on primary science education - its purposes, curriculum, scope for improvement, personal concerns.

These are intended to provide a series of perspectives on each teacher’s professional identity, and their accommodation of science teaching into it. Mutual corroboration and consistency between the perspectives would provide strong support for the existence of such an identity, and throw light on its nature and its relationship with science teaching: it could be argued that this is a kind of triangulation. Elliott (1990) argues that case studies vary in focus, method, and conceptual level, and that the internal validity of individual studies depends on accuracy of description, and the relevance of what is selected for

description: here are five case studies which are at least consistent in these respects, and hence should be readily comparable.

Triangulation between case studies and survey is central to the overall research design, as described above. The case study teachers' answers to the survey questions could be compared with their extended discussion of overlapping issues in interview, enabling the internal reliability and validity of the survey instrument to be assessed with some confidence. The external validity, or at least the typicality or otherwise, of the case studies can then in turn be assessed by locating each case study teachers' survey responses within the frequency distributions for the sample as a whole. The potential problem with this design is the possibility of interaction - does completing the survey change responses in interview? Or are survey responses different as a result of being involved in case studies? It is clearly not possible to arrange for the survey form to be seen by each case study teacher as it was by the other survey respondents, with no preamble or context other than its covering letter. Nor is it possible to prevent interaction. The approach adopted was:

1. To stress the case study participants' 'guinea pig' role with regard to the survey questions, down-playing its structural significance within the project. In other words, participants were allowed to believe that the reason for their filling in the form was to validate its intelligibility: this is acknowledged as a transgression of the ethical ideal of fully frank and open communication with participants, but it was felt to be both fairly innocuous, and necessary to encourage participants to answer survey questions with similar levels of disinterest and casualness as would be likely to be found amongst other respondents.
2. The different circumstances, ways, and levels of care in and with which the participants completed the survey forms were carefully noted; as were the references in interview to things mentioned/answers given in the survey. This meant that data were available through which possible interaction could be investigated as and when it was suspected.

5.5.2.2 Systemic grammar networks

The use of systemic grammar networks or 'systemic nets', an analytic notation and means of making manifest a variety of relationships between concepts (Bliss and Ogborn, 1979; Bliss et al., 1983), in designing the questions and analysing the responses, can act as an aid to external reliability, in that it records and makes explicit the concepts and conceptual structures deployed in these processes, rendering them to some extent accessible to external observers; and to internal validity, in that it can guarantee that a category system used or developed in analysis is both necessary and sufficient to accommodate the data for which it is developed (see Lunn and Solomon, forthcoming).

In the design phase, some rationale or understanding always underlies the preparation of the interview schedule and pre-amble, or survey questions: the more explicit and systematic this understanding can be made, the better. See below for examples of how an initial understanding of the domain was mapped using systemic nets.

In data analysis there are two besetting sins - 'finding' things that are not there, for example by interpreting ambiguity in your favour; and 'cherry picking', selecting and reporting on only those items that fit your hypothesis, and ignoring the rest. With the inevitable ambiguities in recorded and transcribed natural speech, and with the very large volumes of data involved, both sins are easy to commit and difficult for others to detect. Thus in analysis and interpretation, the core requirements for internal validity are to find *only* things that are there in the data or can be convincingly abstracted from them, and to find *all* the relevant things that are there in the data, whether or not they fit with what you want or expect to find: again the more explicit this process can be made, the better. Lunn and Solomon (forthcoming) reports the results of applying this approach to the interview data gathered in the pilot study.

The pilot study used the approach throughout design and analysis. It was found to be useful but time-consuming, and so was applied more selectively in the main study - though it was still widely used, both in design and analysis - for example in preparing interview schedules, and in developing the category systems produced from and

accommodating each teacher's theories of learning. The following paragraphs give a brief description of the technique, and some examples.

Systemic grammar networks provide a graphical method of representing conceptual and category systems. They were developed in linguistics as a means of describing the relationships between units at different ranks of a language, where language is viewed as a system of context-embedded meaning-creating choices. A full description of the technique can be found in Bliss et al (1983), and an overview in Koulaïdis and Ogborn (1988). The basic constructs used here are *single choice* (also known as choice between alternatives, though the number of options can be greater than two), and *parallel* or *simultaneous choice* or *co-selection* (another construct, recursion, is defined, but is not required here).

The symbol for 'single choice', i.e. choice between mutually exclusive categories, is the square bracket, known as 'BAR': this can be read as 'choose one and one only of ..' the terms it encloses, and is used as in the following example:

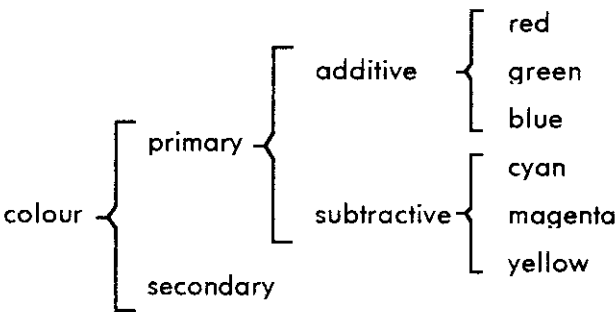


Fig 1: Systemic net - examples of BAR (choose one and one only)

Each branching point in the network represents a choice of one from a number of possibilities: the network could be read

a colour is primary or secondary; a primary colour is additive or subtractive; an additive primary colour is red or green or blue; a subtractive primary colour is cyan or magenta or yellow.

Similarly, classifying any one colour would lead to following one and only one path through the network. The 'delicacy' or fineness of distinction of the network increases

from left to right; and properties are inherited in the same direction, e.g. anything that can be said of colours in general is inherited by all nodes to its right; anything that can be said only of additive primary colours is inherited only by red, green and blue.

The other main construct used here is that for parallel or simultaneous choice or co-selection, whose symbol is the rounded bracket, known as 'BRA': as used by Bliss et al and Koulaidis, this indicates necessary co-selection, and can be read as 'choose all'.

Given that the instantiation of a bracketed term can be 'absent' when that term happens to be inapplicable in a particular context, this is essentially equivalent to 'choose any number of ...' the bracketed terms. It is used as in the following example:

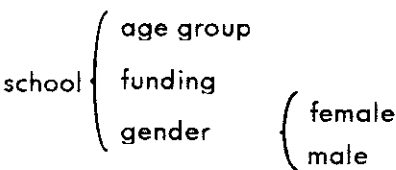


Fig 2: Systemic net - examples of BRAs (choose any number)

to be read as

a school can be characterised by the age group it serves, how it is funded, and the genders of its pupils, which may be male and/or female.

'BRAs' (round brackets, meaning 'choose any number') can be combined with 'BAR' systems (square brackets, meaning 'choose one and one only') as below. This example can be read as:

a school can be characterised by the age group it serves, how it is funded, and the genders of its pupils: age group is either primary or secondary: if primary, it is either infants or junior or both: funding can be LEA, GM or Independent: the school's gender make-up can be single sex or co-educational: if single sex, it will be either female or male.

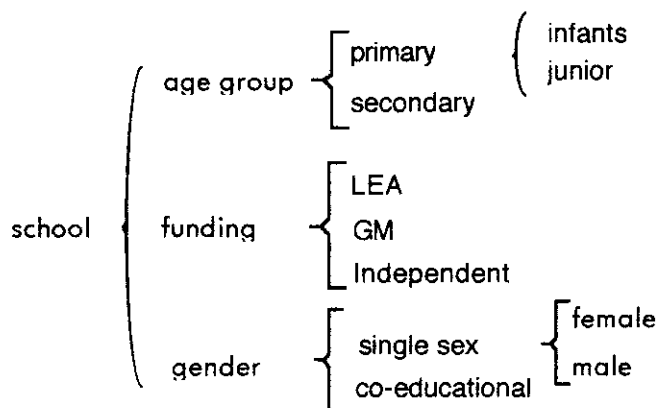


Fig 3: Systemic net - examples of BARs and BRAs

Other important notions are those of the 'paradigm' or path through the network, and 'instantiation', the 'binding' of an instance to a category, or more generally to the category system of a paradigm. For example a paradigm might be as highlighted in the following:

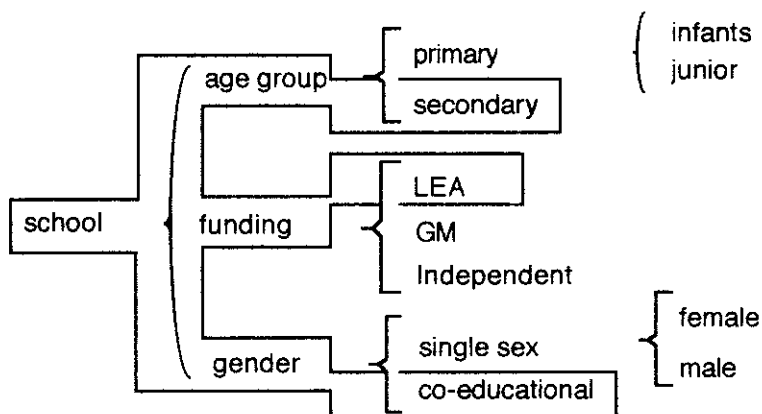


Fig 4: Systemic net - example of 'paradigm'

i.e. co-educational, LEA-funded secondary school. An instantiation of the paradigm might be the co-educational, LEA-funded Moortown Comprehensive School.

At the beginning of the pilot study a 'domain map' was produced, a mapping of the domain of interest in this project - the teachers' science background, their understandings of the nature of science, their views on the purposes of teaching science in primary schools, and the sorts of progression they look for in their pupils. The top-level structure of this domain was represented as follows:

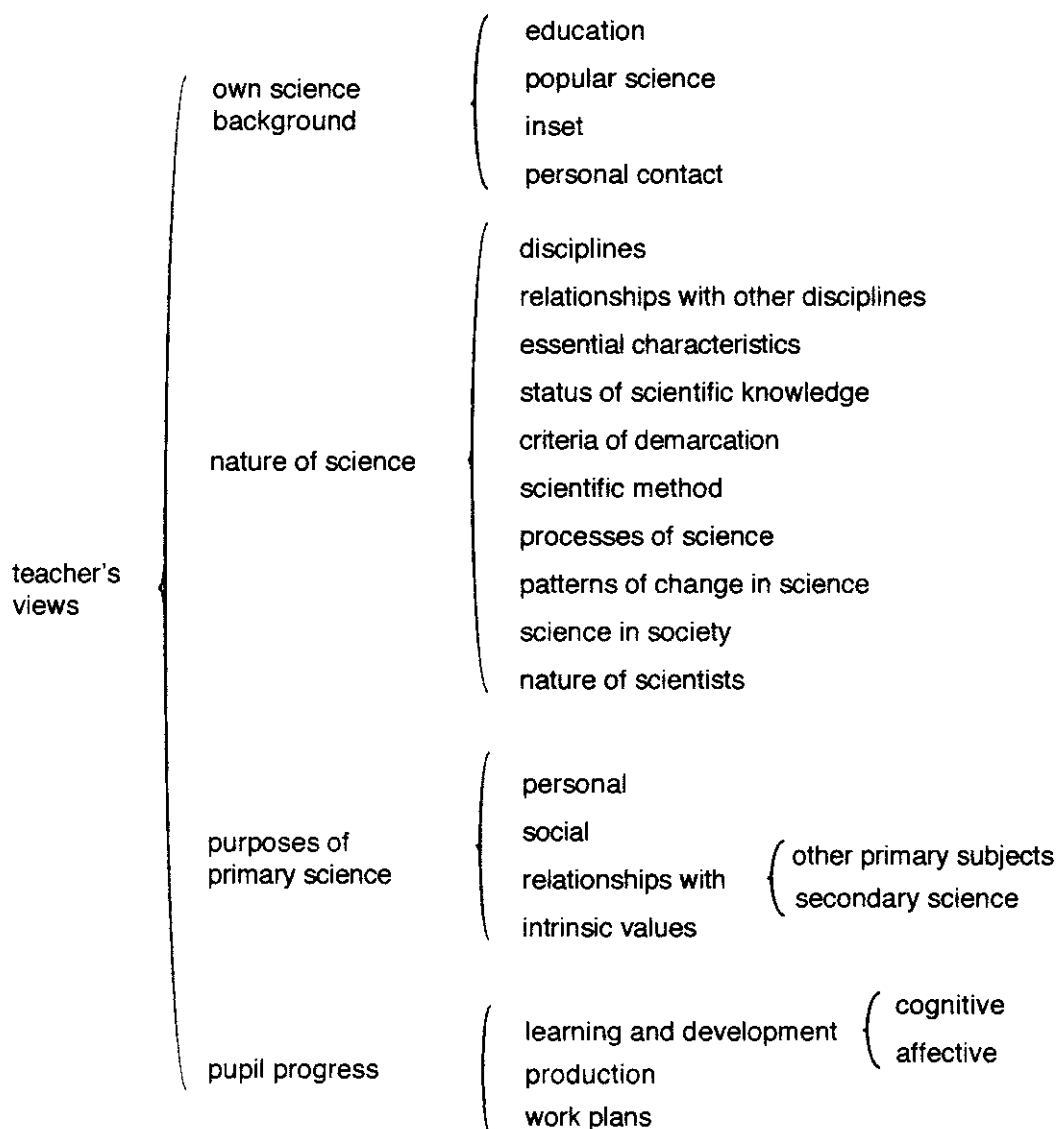


Fig 5: Top-level domain mapping produced at start of pilot study

This can be read as follows:

the areas of interest are teachers' perceptions of their own science background, in particular of their education, their contact with popular science, their in-service training, and their personal contacts with scientists; of the nature of science, in particular the disciplines that constitute it, the relationships between science and other disciplines, its essential characteristics, the status of scientific knowledge, the criteria of demarcation separating science from other activities, the notion of scientific method, the processes of science, patterns of change in science, the place of science in society, and the nature of scientists; of the purposes of teaching science in primary schools, in terms of personal (i.e. relating to the individual child) and social

purposes, its relationships with the purposes of other primary subjects and with the purposes of secondary science teaching, and its intrinsic values; and of pupil progress in science, in terms of learning and personal development, both cognitive and affective, pupils' productions, and the reflection of progression in teaching work plans.

The terminal elements in this top-level mapping can be broken down into more detailed models which are said to be 'nested' within them: for example in the path "teachers' perceptions/nature of science/status of scientific knowledge", the 'status of scientific knowledge' terminal might be defined as follows:

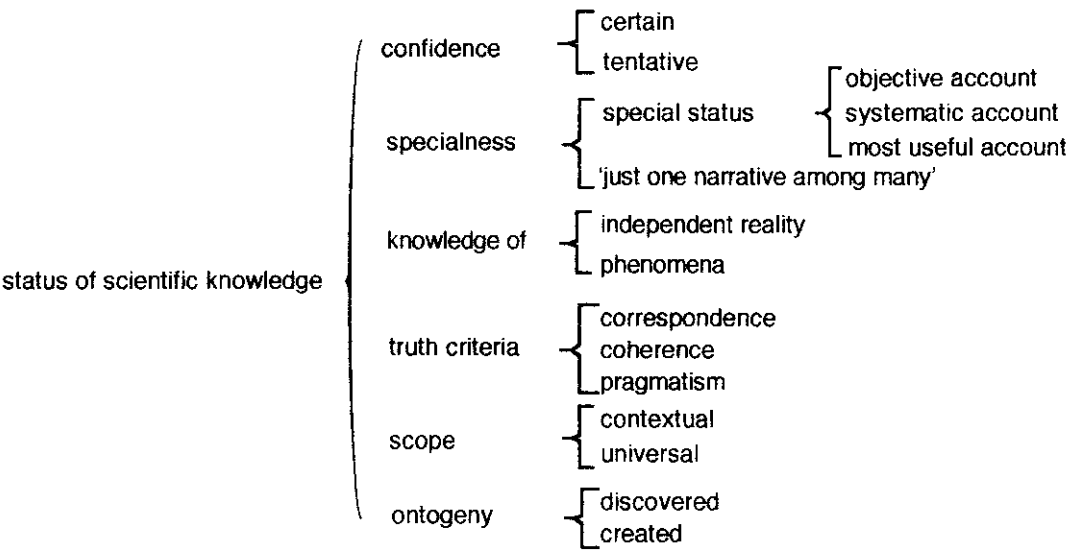


Fig 6: Systemic net for initial mapping of 'Status of scientific knowledge'

This can be read as claiming that:

someone's views of the status of scientific knowledge can be characterised in terms their views of the degree of confidence with which it is held, which may be tentative or certain; the 'specialness' of scientific knowledge in comparison to other forms of knowledge, where it may be seen as having special status due to its presenting an objective account, a systematic account, or the most useful account of phenomena, or as having no special status, but being 'just one narrative among many'; what it is that science provides knowledge of - an independent reality, or phenomena; the criteria by which the truth of a scientific claim may be established - correspondence with an independent reality, coherence within a larger body of knowledge, or pragmatic usefulness; the scope of scientific knowledge claims - contextual or

universal; and the ontogeny of scientific knowledge - whether it is discovered or created.

Nesting (the way in which a terminal in a higher-level network can itself contain or be defined as a lower-level network) and modularity (the way in which a network defined in one place can be re-used in another) are important properties of systemic networks.

5.5.2.3 Verification by independent readers and coders

Internal reliability - the question as to whether, for example, independent researchers would match constructs to data in the same way - is easier to verify than external reliability, in that it involves only re-coding data, rather than re-gathering it. In this project several attempts were made to improve internal reliability by involving other people, as follows:

1. Two people other than the author read through all the case studies, and several others read through some, in order to assess them 'holistically' - i.e. did they seem to be talking about plausible, whole people?
2. Extracts from the case studies were presented to a group of four social science research students, who were then asked to match a series of quotes from case study participants and others, to the extracts they had seen.
3. 'Open' questions in the survey responses, and two 'indicators' derived from the case study data - one relating to the match between each teacher's personal theory and their practice, one to the relative degree to which each matched some external criteria of professionalism - were subject to 'blind duplicate coding' by independent persons, which resulted in good levels of agreement.

5.5.2.4 Personal qualities of the researcher

Elliott (1990) says that "sincerity, honesty and self-awareness are necessary conditions of valid symbolic description at the 'experiential level'", to which 'discipline' might be added, when working on five case studies in parallel.

5.6 Summary of Research Plan

The overall plan for data gathering - the case studies, intersecting at 8 below with the survey - was as follows:

1. Recruitment, access and initial briefing of participants
2. Initial interview
 - discussion of the project: history, objectives, anonymity, confidentiality, verification, feedback
 - planning a science unit/1
 - arrangements for classroom observation
3. Classroom observation 1
4. Participant receives 'Project Pack' containing:
 - 'briefing notes'
 - 'journal' for recording notes, queries, comments
 - transcript of interview 1
 - notes on observation 1
5. Second interview
 - discussion of observation and interview transcript
 - personal science- and education-related biography
6. Participant receives transcript of interview 2, and survey questionnaire with covering letter.
7. Third interview
 - discussion of any queries on or issues arising from completing questionnaire
 - nature of science
8. Postal questionnaire to OU course E833 students

9. Participant receives transcript of interview 3
10. Fourth interview
 - reflections on teaching
 - perceptions and purposes of primary science
 - evaluation of primary science curriculum
11. Participant receives transcript of interview 4
12. Interview 5
 - reflections and comments on transcripts
 - planning a science unit/2
 - reflections on the project
13. Observation 2.
14. Participant receives transcript of interview 5 and observation 2, feedback form, and letter of thanks, offering optional debrief and discussion.
15. Participant receives summary of survey findings, and invitation to comment.

Detailed backing information - e.g. interview schedules, questionnaire, dates, times and durations of interviews - will be found in the appendices.

5.7 Design and execution of survey

5.7.1 Survey sample

The sample for the pilot study was small and partly self-selected: it was felt necessary to survey a larger sample, to find out how views expressed in interview were distributed in the wider population of primary teachers, and to support the external validity of the main case studies.

5.7.2 Questionnaire design

Most of the questions in the survey were derived from the words of the seven teachers interviewed in the pilot study. The questionnaire design was piloted through five revisions with eight ‘guinea pig’ teachers. Self-completion postal questionnaires were sent out in Spring 1999, to the students registered on the Open University course ‘Assessment and Planning in Primary Schools’ (OU course code E833, part of a Masters course in the School of Education) in 1998, following discussions with the OU course manager. Respondents were thus not a *random* sample of the primary teacher population. If anything the sample was biased in favour of teachers interested in their own professional development and in their personal contributions to their schools; but it was not biased in any way with respect to science or science teaching, and thus is treated here as a representative sample in this respect, in assessing confidence limits and significance of generalisations from this sample to the wider population of primary classroom teachers. Steps were taken where possible to assess the reliability of this assumption - for example the gender mix of the respondents was compared with that of the primary teacher population as a whole (DfEE, 1999), and found to lie within the 5% error bars. Similarly, levels of qualification in science, and rankings of subjects by ‘level of comfort’ or perceived competence, can be related to similar measures of the primary teacher population derived from other sources (de Boo, 1989, 1997; Wragg et al, 1989; Bennett et al, 1992).

The survey asked for the following kinds of information:

Background variables	e.g. age, gender, year qualified, number of years teaching, number and age of children taught, subject co-ordinator, number of hours of science taught per week
Contacts with science in own education: primary, secondary, tertiary	details such as science GCSEs, subjects taken to A level; and feelings about science when at school, by way of agreeing or disagreeing with statements such as

	<p>“Science was daunting”, “Science was not a subject for girls”, on a five-point scale (1=strongly disagree, 2=disagree, 3=not sure, 4=agree, 5=strongly agree)</p>
Contacts with science outside education	e.g. level of interest, following in media
Views about the nature and status of science	<p>7 blocks of statements, 4-6 statements per block, each with a 5-point level of agreement scale. Blocks correspond to:</p> <p>1 & 2: status and objects of scientific knowledge - e.g. factual rather than opinion; knowledge of ‘reality’ or phenomena</p> <p>3: ontogeny - e.g. ‘from the data’, or negotiated consensus between specialists</p> <p>4: acts of faith underpinning science - e.g. that the universe is orderly and consistent</p> <p>5: role of experiment - e.g. scientists usually have no idea what is going to happen</p> <p>6: status and ontogeny of theory - e.g. well-established explanations; come from the imagination of scientists</p> <p>7: progress in science - e.g. comes from steady accumulation of facts; or new ways of looking and talking</p>
Critique of the National Curriculum for science	Should it be changed? If so how?
Views on primary science teaching in general	Importance of subject knowledge; purposes of primary science education.
Personal experiences of primary science teaching	Raising topical or extra-curricular issues; dealing with questions; professional development; level of comfort with various subjects; main concerns when preparing a science topic.

The issues to be addressed using the survey data included teachers' ranking of science in terms of their level of comfort in teaching it; their perceptions of the nature of science and the purposes of primary science education; their views on the role of subject knowledge in primary science teaching; their views on the development of the curriculum and of their own science teaching; their main concerns in relation to science teaching; and any relationships between these.

5.7.3 Data collection, preparation and analysis

Survey forms were distributed and collected by the OU Survey Office. A covering letter and survey form were sent out on 27th January 1999; a reminder card on 11th March; and a final reminder and replacement form, in case the first had been mislaid, on 31st March.

Of 143 forms sent out, some 60 went to people who were not full-time class teachers in primary schools in England and Wales - these were variously unemployed, head teachers, deputy heads, LEA advisors and inspectors, etc. Initial analyses showed that their responses were frequently incomplete, for good reasons - many had little to say about science teaching because they did not do any. It was thus decided to exclude all those who were not full-time class teachers from analysis. Thus the survey form was sent to 83 full-time class teachers in primary schools in England and Wales. Of the 95 usable forms returned, 61 were from such people, so the response rate was around 74% for this subset.

The data were typed directly into SPSS and verified. Clearly anomalous returns were excluded, e.g. where subtraction of 'years of experience' from 'age' suggested that someone had started teaching at the age of five.

The data were analysed using SPSS and MS Excel during September 1999 to March 2000.

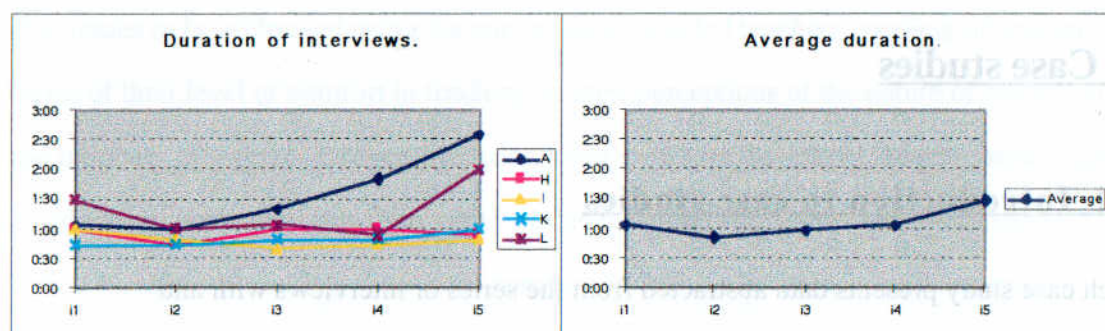
6. Case studies

6.1 Introduction to case studies

Each case study presents data abstracted from the series of interviews with and classroom observations of each of five teachers (of the seven teachers originally involved in the project, two withdrew at an early stage, and are not included here). All interviews and observations took place in the teacher’s normal classroom; all interviews started soon after end of the school day. The sequence and foci of interviews and observations with each teacher was: interview 1 - planning; observation 1; interview 2 - life history; interview 3 - nature of science; interview 4 - primary science; interview 5 - planning re-visited; observation 2. The number of months over which this sequence was spread, and the total durations of interviews and observations, are as follows (details of dates and durations of individual interviews and observations can be found in appendix 3):

	Elapsed time from first to last	Total duration of interviews and observations
Andrew	18 months	9hr 55
Howard	14 months	8hr 50
Irene	16 months	6hr 00
Keith	16 months	6hr 00
Linda	13 months	10hr 10

The initial interview with most participants was slightly stilted at first, as mutual exploration took place. Conversations became more friendly, flowing and fun as time went by, to the point where at times it was difficult to bring a session to a close without being rude. Interviews varied in length from 40 minutes to over two-and-a-half hours, compared with a planned (and agreed) duration of 30 to 60 minutes (see the briefing pack issued to participants in the appendices).



This may be related to the nature of the conversations, which from the outset and increasingly probed the participants' professional 'hearts' - their self-images, values, senses of self-worth as teachers - calling for deep reactions which consequently involved them in investing a considerable degree of trust in the interviewer, if they were to go through with the project. Such an act of trust may have engendered feelings of friendship towards the interviewer, perhaps even a modest kind of 'positive transference' as described in psychotherapy (e.g. Storr 1979), and led to extended interview times both by the injection of repeated 'friendly digressions', and through making the conversations generally more relaxed and discursive. Though such feelings were not necessarily justified by the interpersonal transactions in which they were engaged, they may have been necessary concomitants of the acts of trust demanded by engagement in the project, and equally necessarily led to certain tensions when the time came for withdrawal from the relationships created during the project, similar to those ethnographers encounter when 'leaving the field' (Hammersley and Atkinson 1995 p120ff).

The two teachers who dropped out (one after one session, one after three) perhaps found it more difficult to trust; or perhaps felt more vulnerable and thus needed to trust more, and were unable to do so without real grounds. Perhaps coincidentally, in both cases their withdrawal from the project followed immediately on their appointments as literacy co-ordinators, charged with implementing the 'literacy hour' in their respective schools.

This chapter contains case studies of the five teachers who saw the project through. The order in which they are presented is not significant. Each is abstracted and condensed from the transcripts of a series of five interviews and two lesson observations conducted between February 1998 and July 1999. Each covers:

- the teacher's life history, self-image and values;
- their theories of learning, as described, and as deployed in the classroom;
- their views on teaching in general
- their views on primary science education
- their views on the nature of science;
- their reflections on the experience of taking part in the project
- notes on other interesting issues or aspects.

Detailed transcripts of interviews and descriptions of observed lessons are available on request. References to paragraphs in the original transcripts and descriptions are given in the following, to allow traceability: for example (int2#138, int4#231-#239) refers to interview 2, paragraph 138, and interview 4, paragraphs 231 to 239.

6.2 Irene

Now in her early fifties, Irene qualified as a teacher in 1994, and had taught in two other schools before joining her present school in 1997. At the start of this project she was in her fourth year of teaching: by the end she had completed her fifth.

She teaches one of three Y6 classes. Her classroom is on the top floor of the tower block of a middle school, on the fringe of the 'inner city'. Though not much more than a mile from Andrew's school, its catchment area is less 'leafy suburb' and more 'ex-council estate'. Around 30% of pupils in the school are from ethnic minorities.

The class consists of 30 children. For the purposes of science and other 'non-setted' subjects they work in mixed ability groups or pairs, or as individuals. She divides the spectrum of abilities in the class into three main levels: at the top end four "really able" girls, who are given considerable autonomy, and for whom extension tasks must always be provided; in the middle the majority of the class; and at the lower end one "statemented" child, and "the children with English as a second language .. it's not that they're not able, it's the language problem" (int5#8-#12, #24-#26).

She divides the class into three different sub-sets on another dimension: “really caring children, who really make me feel warm inside.. others couldn’t care less about anything; and some couldn’t even care less about themselves, who’ve got no value, no self-worth”. (int5#232)

The room has some lively displays, which move on during the project from ‘The Victorians’, City-scapes, and 3-D cubes and prisms hanging from the ceiling, to ‘The Weather’; literacy hour; tessellation; forces; cat family and desert pictures; numerals and their names; and profile silhouettes.

6.2.1 Life history, self-image and values

6.2.1.1 Life history

6.2.1.1.1 Primary, Secondary and Further Education

Irene grew up in ‘a very small village’ on the south coast in the 1950s, and went to the old ‘Victorian’ village school, which her children were also later to attend. She has no memories of science being taught in her time there. (int2#138, #231-#239)

She moved on to a secondary modern school in a local town where she became interested in biology. She was thinking about a career in nursing, when the Headmistress “gave this spiel about ‘The country needs scientists, you’ve got to do your bit for the country’.. that’s when I thought ‘Yes, that’s what I’ll do, I’ll go into science’”. Motives of patriotic or civic duty coincided with an interest in the world around her, and she decided to take all three sciences to GCE O level: she has since regretted not taking history or geography. (int1#296, int2#76, #124)

The flat tone in which she relates the fact that she passed biology but failed physics and chemistry O levels may suggest that time has still not entirely healed the feelings of disappointment and deflation that accompanied this news. She left school to re-take physics and chemistry at a college of further education. This time she passed, and at eighteen left college to take up her first job. (int1#296, int2#76)

6.2.1.1.2 First Career - Lab Technician

Irene first worked as a laboratory technician at a local girls' high school, taking a three-year day-release course for lab technicians at the local college. She gained a wide range of technical skills, in "metal work, wood work, glass blowing, you name it ..", and she came to derive great enjoyment and satisfaction from using these skills to create good quality work. In due course she gained her lab technician's certificate, and as the school expanded got an assistant whom she trained 'on the job'. (int2#76, #78).

By this time Irene was married. She spent six years 'out of work', looking after her two children while they were small, then went back to work part-time in a residential 'American college' in the south-east. She loved the very multi-cultural atmosphere, and enjoyed working on the biological courses involving fieldwork and collecting trips, through which she gained great confidence in her knowledge of natural history: "I got to the point where I knew exactly which stone to lift in the river bed to know where I'd find a particular animal". (int2#78-#98)

She moved with her family to a city on the south coast, and got a job as a lab technician in a comprehensive school. She worked with an assistant, looking after all laboratory requirements for all three sciences, and had some bad experiences with the older children. (int2#100, #126)

At about this time she got divorced and had to find a better-paying job. This materialised in the form of a pharmacology technician post in the pharmacy department of a nearby university. Not knowing much about pharmacology, she bluffed her way through the interview, and it was not until she had started work that she realised what was really entailed in the job, and that she had to make a moral accommodation to using animals in research. (int2#104)

While there she studied part-time to gain an ONC in Biochemistry, then an HNC in Applied Biology. She 'really loved' the job, particularly enjoying the careful, accurate measurement of chemicals and drugs, until "I suddenly thought.. my generation has ruined the world, we've consumed everything, polluted everything.. it was a very altruistic point of view and I've changed my mind a little bit now, but I felt if I could

teach the next generation to put it right, to know what to do and at least to make them care so they do something about it, then I'd have perhaps put back a little bit of what my generation has done wrong. So I just sold everything, upped sticks and went. I did a four year BEd course and specialised in environmental science and that's how I became a teacher." (int2#104)

6.2.1.1.3 Becoming a Teacher

Her son's experiences of studying in Liverpool had shown Irene that surviving on a student grant there was possible: and her GCSEs, ONC and HNC satisfied the entry requirements. The grant would have been higher and the course two years shorter had she elected to train as a secondary science teacher, but her 'awful' experiences at the comprehensive had put her off and she chose primary. (int2#104, #106, #126, #130-#132)

As part of her degree she prepared a 20,000-word thesis entitled "How green are our children?", where she concluded that children get most of their environmental knowledge from the media rather than from school.

Her daughter graduated at the same university the day before she did: Irene describes the days of the degree ceremonies as the proudest of her life. (int1#296, int2#108-#110)

6.2.1.1.4 Working as a Teacher

Irene feels that her strength in science and particularly in technology have helped her to get teaching jobs: she runs a craft and technology after-school club at present, and would run a science club as well if she had time. (int2#136)

She enjoys and feels most confident in teaching science and technology, finding maths and English more difficult because of having less 'background knowledge'. She rejects the idea of subject specialists, while acknowledging that it is hard to have deep background knowledge in everything. (int2#142-#144)

She describes the 'best buzz' of her teaching career as the culmination of a year's efforts to 'unfreeze' a child who had been sexually abused and who refused all physical contact:

“he actually came and hugged me goodbye, and I felt ‘I’ve come so far with him, he trusts me now’.. I love to gain the children’s trust, I love to”. (int4#81)

In her present position Irene is on a one-year contract which has been renewed once: there is no guarantee that it will be renewed again, so she is actively looking for another job, concentrating on primary (as opposed to middle) schools.

(Note: Irene was subsequently given another one-year contract, and has another Y6 class. She has now become a ‘science specialist’, taking all three Y6 classes for science.)

6.2.1.2 Self-image

Irene sees herself as someone who:

- has always been interested in and curious about the natural world (int2#76)
- finds great enjoyment in life, especially in using her skills and knowledge to do high-quality work (int2#78, #96-#98)
- is brave and foolhardy (int2#106)
- has to an extent sacrificed her own interests to the common good (int2#124)
- is sceptical of what she finds in the media (int3#34)
- is especially good at “the pastoral side” of teaching, being able to empathise readily with children and others (int4#79)
- approaches teaching with humility, in her preparedness to learn from the children, and is not a mathematician (int1#204-#218)
- champions ‘green’ values, ironically referring to this as her ‘hobby-horse’, and explicitly linking it to her vocation for teaching, of “trying to educate them for a better world” (int5#30, #58, #138)
- is to some degree a science specialist, pointing out that she is qualified to and does teach science up to Y8 (int5#228).

6.2.1.3 Values

Various values are implied by Irene's account, for example:

- 'green' values, with collective responsibility and individual accountability (int2#42, #104)
- valuing accuracy and precision (int2#104)
- valuing ceremony and formal recognition (int2#108-#110)
- treating children fairly and as sensitive individuals with personal rights (int2#128)
- a deep and loving concern for children, referring to them in the warmest terms (int2#36-#38)
- an impulse towards, and duty of, care and respect for the natural world (int5#244, obs2#138-#142).

She also feels strongly that, in transactions with children, there is nothing more valuable an adult can give a child than time. (int5#244)

6.2.2 Theories of learning

6.2.2.1 In planning and discussion

Irene calls on five principles in talking about her children's learning:

- the importance of vocabulary, especially the special 'scientific' uses of words known from other contexts
- the importance of the children's active engagement, with their own eyes, hands, ears, noses and voices
- the importance of connecting their science learning with their experiences in other science topics and elsewhere within and outside school
- the central role of confidence in children's learning
- the importance of encouraging appropriate kinds of social interaction between pupils.

She believes that the relative importance of concrete experience and exploration on the one hand, and making connections with prior knowledge and experience on the other, changes in favour of the latter as the children move through from Y1 to Y6. (int1#10-#296, int2#150)

6.2.2.1.1 Vocabulary

She stresses the need to think about how new meanings fit in with the meanings the children bring to the situation, and describes her practice of introducing a new word with a discussion of its etymology and examples of how it is used, together with physical demonstrations if appropriate - immediately embedding the word in a network of semantic and episodic connections. (int1#194-#196, int5#152-#158)

6.2.2.1.2 Engagement

Irene stresses the need for children to actively engage in their own learning, to explore, experience, enjoy and communicate about their science, with as much concrete experience as possible: "I think children learn so much more from doing things. They remember. Even if it goes wrong they still remember it, they have a laugh, and that'll still stick in their minds.. learning has to be fun .. if you make it a bore they don't want to do it!" (int1#10, #140, #164, #296, int4#197)

At the upper end of the primary age range it is most important for the children to engage with what goes on in the classroom as active learners, knowing and negotiating what they are doing, why, and how it fits in. If they haven't asked themselves the question, they are going to gain little from being told the answer to it, so the teacher's job is to iteratively guide the children closer and closer to asking the right question, and let them feel that they have, in some degree, both defined the question and discovered the answer for themselves. (int4#73, #135, int5#234)

An interesting sidelight on engagement is cast by the remark that "children don't learn by being totally silent, they need to interact with each other", suggesting that learning arises out of discourse. (int4#37)

6.2.2.1.3 Making connections

Irene continually tries to connect the science she is teaching with other topics in science and other subjects, and with children's lives outside school (e.g. int1#42, #44, #66, #80). She actively proselytises this approach, on one occasion giving me an article from a professional journal (Cross, 1999) in which she had highlighted phrases about connecting science with everyday life (int4#1).

She argues that:

- children understand by relating what you are teaching to what they already know
- learning that is unconnected to what they already know is no more than rote memorisation
- children learn better if you can get them to bring up the answer, particularly by way of the kind of social interaction that she refers to as “bouncing ideas”. (int1#70-#76, #140, int2#36-#38)

Irene tries to connect and contextualise the scientific *content* which she is imparting to the children, relating it to local and personal as well as global and topical issues, and ensuring the moral dimension is considered. She seems less sure about the need to contextualise pupils' *practical investigations*, or what it would mean to do so. (int4#93, #111-#119, int5#56-#58)

6.2.2.1.4 Confidence

Confidence influences and interacts with children's learning in that:

- 'knowing how to' is no good without the confidence to 'have a go'
- confidence in one sphere helps learning across the board
- negative feedback creates a cycle of failure and lack of self-belief. (int1#104, #108, #158, #246, #271)

These imply that her theory of learning positions the child as an 'active learner', and that it is important to set tasks at which children can succeed.

Also she values the situation where a question comes up that she is unable to answer, as an opportunity to help build children's self-esteem and confidence, and to develop a realistic idea of the extent and limitations of anyone's (including adults') knowledge. (int4#69)

6.2.2.1.5 Social interaction between pupils

Irene has definite ideas about how grouping children influences learning, especially in 'doing' subjects like science, where grouping is at the teacher's discretion. She is keen to ensure that groups are mixed ability and single gender, so that children learn from others and by helping others, and so that no one gender can dominate or be dominated in each group's activities. (int1#152)

6.2.2.2 Deployment of theories of learning in teaching

There is no reason to suppose that all a teacher's personal theories should or could be deployed in all lessons: those that appeared to be deployed in the two lessons observed are described below.

6.2.2.2.1 Vocabulary

In both observed lessons, the dialogue seemed to have a cyclical pattern as follows:

- set up a context
- ask a question
- solicit a number of answers
- evaluate/approve/indicate the 'right' answer in this context
- elaborate and make connections with children's personal experiences, home life, broader issues, and other things they have learned in school, in science and other subjects, often involving dramatisation and colourful demonstration
- use one of these connections to set up a new context, and enter the cycle again.

Many of the starting points for these cycles were to do with the meanings of words, often their special meaning in the science context. Their results were to embed the words

in networks of conceptual, emotional and moral meanings (e.g. obs1#63-#67, obs2#36-#62). Irene was unaware of the nature of these cycles until I pointed them out to her as we discussed the lesson description, during the interview following the first observation (int2#29-#36).

6.2.2.2.2 Facilitating children's engagement with their own learning

This is manifest in:

- Irene's clear explanations of 'What we are doing and why we are doing it', giving the children a valuable perspective on, and perhaps a slightly greater degree of control over, their learning: this includes sharing with the children the constraints imposed by SATs and the need for revision (obs1#4, #136)
- Irene's welcoming, valuing and using everyone's contributions to the discourse, wherever they might lead (almost) (e.g. obs1#53-#61).

6.2.2.2.3 Making connections

Connections between the science she is teaching and going to teach, and other topics in science, other subjects, and the children's lives outside school, are everywhere in Irene's teaching. For example in a three-minute dialogue cycle about 'healthy diets', she makes connections with the 'eat up your greens' discourse many will have encountered at home; overcooking vegetables; information and advertising in chemist's shops; dental health; children's love of sweet things and its consequences for teeth; T.V. adverts for cheese spreads; calcium and other minerals; the Victorians topic they have recently done in Humanities; vitamin and mineral deficiencies, and the 'Enriched with vitamins and minerals' text they will have come across on the sides of cereal packets; and children's diets in the 'third world'. (obs1#14-#28) Again the effect is to embed the concepts in networks of personal, conceptual, emotional and moral meanings.

6.2.2.2.4 Building children's confidence and sense of self-worth

Irene accepts and values everyone's contributions, often building children up by telling them that she had never thought of it that way herself (obs2#22-#24).

All the children in the group succeeded in completing the main tasks (e.g. obs1#138-#140), implying that the task was set so as to be within the scope of everyone in the class.

Children were given personal one-to-one time during and after lessons (e.g. obs2#272-#276, #311-#313).

6.2.3 Teaching

6.2.3.1 Images of Teaching

Irene's generic image of primary teaching has children working in groups, possibly on different tasks, with fairly quiet talk going on between children. The teacher would be circulating, making sure that everyone knows what they should be doing, are doing it, and get any help they need. If science were being taught she would expect to see more direction and guidance, and more specific teaching of skills. A mark of a 'good' lesson, in science or otherwise, would be the teacher leading frequent 'off task' digressions, pursuing lines of thought instigated by her or by the children. (int4#37-#51)

6.2.3.2 The role of subject knowledge

Irene acknowledges a central role for subject knowledge in teaching, particularly the background knowledge that allows the interesting digressions that are her hallmark of good teaching; but recognises that it is not possible to be 'a specialist in everything'. She believes that this does not preclude teaching without deep background knowledge, arguing that the benefits of the 'single class teacher' approach at primary level outweigh any problems of patchy background knowledge. (int4#107)

6.2.3.3 Professional Development

She is concerned about her own professional development, seeking out journal articles and relevant Open University programmes on T.V.; and would be keen to learn more about her favourite areas such as ecological fieldwork. She recognises that some kinds of teacher knowledge and confidence can only develop in difficult circumstances, giving an

example of a class of 4- to 7-year-olds acting the parts of bees and flowers, which got “totally out of hand”. (int4#7, #89-#91, #97)

Reflecting on her professional development since she started teaching some five years earlier, Irene says that:

- her approach to planning has changed completely: to begin with she would practically ‘script’ each lesson, whereas now her plan involves knowing what she is aiming for each week, and the main activities and resources that she will use to get there (int5#226)
- she feels that she gains in confidence and competence each time she teaches a topic, gradually building up a stock of ideas and understanding, and becoming more relaxed and less uncertain, knowing what is coming and that she can cope with it (int5#228).

She is aware that some of her colleagues are less confident in science teaching than she is, and is adamant that her theories of learning should be applied to in-service training, offering a warrant based on her experience of running technology courses. (int4#195)

6.2.3.4 Tensions and constraints

Irene discusses the effects of SATs on teaching and children at some length:

- pressure on time - having to teach the whole Y6 curriculum in 1½ terms, to allow time for revision
- pressure on children, especially the more able, from parents
- pressure on staff, especially those teaching Y6, who feel that the school’s place in the league tables, and hence next year’s intake, and hence people’s jobs, depend on them
- displacement of teacher attention onto the grade 3/4 and 4/5 borderline children, at the expense of the rest. (int1#84-#88, #120-#124, #126-#134, int2#150, #162, #168-#178, #184, #186)

6.2.3.5 Reflections on teaching

She believes that her teaching can influence the kind of people the children are growing into, by shaping their values and awareness of self and others, seeking to make them:

- more caring and respectful towards each other and the environment
- more able to put themselves in another's place and understand how they feel
- more able to slow down, reflect, savour and enjoy life (int5#30, #238).

She argues that “just pouring information into them” is no way to teach science: rather she aims to “light the fire” of interest and ideas, enabling them to become autonomous learners. She regrets that school, home, the media and the modern world conspire to squeeze out opportunities “just to stand and look at something beautiful.. there aren't many children in the world who do that these days”. (int5#240).

6.2.4 Primary science education

6.2.4.1 Purposes of Primary Science

Irene sees the main purposes of teaching science to children in Y1-Y6 as:

- to catch the children while they are still receptive to new ideas, and give them an understanding of the world before they lose interest
- to provide a vehicle for learning how to learn from interacting with each other (int4#139-#151).

The aim is to stimulate and satisfy their curiosity, whereas at secondary level “everything is aimed towards exams, and all the fun is taken out of it”. (int4#155).

Signs of success include children looking forward to and enjoying science lessons, an increasing capacity to work co-operatively with peers, and emergence of a questioning or sceptical stance. (int4#157-#171)

Formal indicators of progression are sought chiefly in the quality of written work, especially in how well they record their practical work (int4#175-#177).

6.2.4.2 Preferred directions for the development of the curriculum and practice in primary science

Irene finds the National Curriculum for science at key stage 2 satisfactory but restrictive, sharing its objectives in so far as she is aware of them, and finding the main constraint to be lack of time because of KS2 SATs (int4#179-#187).

Given a free hand to change the curriculum, she would:

- add an external or social dimension to the science content; incorporate discussion of values; and include a 'green' focus (int4#121)
- allow flexibility for teachers to adjust the curriculum to meet local opportunities and requirements (int4#121)
- allow more time for practical work (int4#131)
- allow time for the children to "use their imagination more" and have fun (int4#133).

A significant problem is that, by the time they reach the end of Y6, most children will have been taught many parts of the curriculum three times, and will thus know it "back to front, upside down". There is a possibility that they may become bored with it. (int5#58)

6.2.4.3 Concerns

Irene's main concern when preparing to teach a science topic is being able to present the concepts at the children's level.

6.2.5 Science

6.2.5.1 The nature of science

Irene sees science as a process (study of the world) with a purpose (to help us understand it): so sees it as a situated, human activity characterised by succinctness and purposeful abstraction, demarcated by being precise, testable and impersonal, concerned with facts rather than feelings (int3#6, #8, #28, #58-#64).

Though seeing science as in principle of equal standing with other forms of knowledge, she believes that in practice it carries more weight in argument, leading her to a sceptical

position towards advertising and official statements, where she feels that an imprimatur of scientific credibility is often 'conjured'. The phrase 'scientifically proven' immediately calls to her mind the context of marketing, persuasion, and vested interests, though she acknowledges its different connotations if spoken by a working scientist, to colleagues. (int3#30, #36, #42-#44, #72)

There is one scientific method common to all science, which in essence involves carrying out an experiment or investigation to find out or rather to verify something specific, since scientists normally have a good idea of what the results of an experiment will be. The method involves working with precision, in an ordered and logical manner, gathering and recording results, and then drawing conclusions - equivalent to creating theory explaining what the results mean. New theory is created by a scientist in order to solve a problem, and though usually greeted with scepticism, will finally be proven, given tenacity on the part of its proponent. (int3#114-#122)

Subject boundaries both within science and between science and other disciplines are artificial and often arbitrary. Cooking is seen as a science on the grounds that it involves chemical change (int3#18), while art is seen as the opposite of science because of its specifically personal and creative nature (int3#28).

Human problems and pre-occupations are seen as providing the 'necessity' which is 'the mother of invention' - technological and medical needs are the engine of change and progress in science (int3#126).

6.2.5.2 The nature of scientists

Scientists are methodical and focused: though perhaps unsure where they are going, they keep trying, motivated by desire to prove their own original ideas, and to do something useful for mankind (int3#128-#132).

Irene consciously rejects the stereotypical image of the scientist as a white Anglo-Saxon male in a lab coat, quoting counter-examples like Marie Curie; but retains the notion of the scientist as being an 'oddball', an original and lateral thinker with different values (int3#14, #130).

6.2.5.3 Science and morality

Science and morality are often in conflict. Commercial vested interests steer and constrain scientific research: the problem is not with the scientists themselves, who generally have human values, but with the industries exploiting scientists' work for profit, which have only commercial values. As humans we have a collective responsibility for what our species does: we have only ourselves to blame if *we* suffer as a result of some new technology, but we have a collective responsibility to protect the natural world, which has no choice in the matter, from such effects. (int3#136-#138)

6.2.5.4 Scientific literacy

Science should matter to non-scientists, who should have some sort of idea of the scientific explanations of why the world is as it is, of everyday phenomena like night and day, the seasons, their heartbeat - "otherwise you're just living in a world of cotton wool" (int3#134).

6.2.5.5 Views of science implicit in planning and discussions

Various comments suggest that Irene sees science in the following ways:

- science is woven intimately into the fabric of her world, familiar and accessible (int1#158, #294)
- unlike parts of maths and English, where repeatedly asking 'why?' will lead eventually to an explanation in terms of an arbitrary rule, science always offers the possibility of substantive explanation (int4#71)
- in the practical sphere of experiments, "science doesn't always work" as one expects and hopes, just as following a recipe does not always produce a perfect cake (int4#87)
- messages about the nature of science and our relationship with it should come through in her teaching - the interconnectedness and interdependence of processes and areas of knowledge within science, of the physical and biological systems of the world, and of our place in and responsibilities towards them (int5#198)

- just as children learn best what they find out for themselves when they have time to “play around”, so do scientists, “but on a much much higher level” (int5#234).

6.2.5.6 Views of science implicit in teaching

The main messages about the nature of science implicit in the observed lessons are:

- that its purpose is to provide explanations for experience (obs1#67-#73): the teleological flavour of some of the explanations offered may reflect a personal theory that such explanations are better understood by children of this age
- that *doing* science, e.g. framing and conducting an open-ended investigation, is hard but worthwhile, compared with rote learning of science ‘facts’ (obs1#2)
- that it is OK to ‘idealise’ what you did when you are writing up your work, so that the written report of an experiment is strictly speaking untrue in what are considered to be unimportant details (obs2#150)
- that you can know what is going to happen before you do the experiment (obs2#34, #78, #104).

6.2.5.7 Science outside school

Irene is interested in and knows the science of AIDS, and has worked as a volunteer with AIDS patients. (int2#209)

She follows everything to do with science in the press and on T.V., and used to take New Scientist but found it went ‘over her head’. She reads some popular science books, is an avid science fiction reader, and would “love to go to Cape Canaveral and see a rocket go off”. (int2#209, #213)

6.2.5.8 Reasoning about a real-world issue: head lice

Irene disagrees with the suggestion that head lice prefer clean hair, on the grounds of biological generalisation and reasoning: all bugs need food; head lice are bugs; there is no food in a clean environment; therefore head lice need a “mucky environment” (int3#142).

She accepts that head lice prefer long hair, again grounding her view in a biological argument: that the evolutionary advantage of any tendency to seek concealment would have led to an instinctive preference for long hair (int3#144).

She is unsure whether head lice prefer girls, but offers an hypothesis that if they do so, it is more likely to be a side-effect of their preference for long hair and the higher incidence of long hair among girls, than the sometimes popular explanation of their aversion to testosterone (int3#146).

She suggests that there might be a social reason for the popularity of the 'head lice prefer clean hair' folk wisdom: "they say it to pacify people, nothing to do with the actual fact". (int3#160)

6.2.6 Taking part in the project

Irene found reading the transcripts interesting and useful: they held up a non-judgemental mirror to her teaching, and showed her new ways of looking at what she was doing. She recognised and reiterated the centrality of 'making connections' in her approach to teaching, and showed signs of having reflected on what was said between sessions. (int2#20-#30, int4#1)

She feels that our conversations have led her to looking at science more reflectively and "more from a moral angle", changing her thinking about what she does and how she does it, and is proud to have taken part in something she feels will be of value. Though not aware of any consequences of this for her actions in the classroom, she points out that children are quick to read implicit messages about a teacher's views, values and identity from everything she does, not all of which are necessarily under conscious control. (int5#230-#232, #252)

6.2.7 Other notes

6.2.7.1 Knowledge of and relationships with children

Irene frequently refers to what she knows and feels about the children in her class and about children in general, making evident her emotional investment in her relationships

with them; and to the usefulness of getting to know them from a variety of perspectives and in a variety of contexts. (int1#108, #266, #271-#275)

6.2.7.2 Imagery

Irene often deployed images consciously in descriptions, for example in talking of various stereotypical images of science and scientists or describing the origin of theories: another kind of imagery seems to involve the recreation of a fragment of classroom dialogue or reproduction of a 'script'. (e.g. int3#14-#16, #28, #122)

6.3 Howard

Howard is in his late forties, and has been teaching for nearly thirty years. At the start of the project he was teaching one of three classes in Y3, and was science co-ordinator and deputy head, in one of four primary schools in a large suburban village in central south England. They did science for a complete morning, once a week. During the project he moved to Y5, and had a difficult year, being moved through a series of temporary classrooms while building work is going on. Science became an afternoon activity as literacy and numeracy strategies took over the mornings.

Howard plans well in advance: at our first conversation in early March he had already planned all three science topics for the summer term. Planning is rooted in the curriculum, with 'bullet points' copied verbatim into the plan "so that we don't get lost"; and draws on an LEA scheme of work and previous years' plans. (int1#3, #7-#13, #19, #29)

6.3.1 Life history and self-image

6.3.1.1 Life stories

6.3.1.1.1 School

Howard attended a "good, very formal" primary school in a suburb of Manchester. He cannot remember doing any science or nature study: his only memories involve kinaesthetic experiences, minor misdemeanours, and getting out of lessons by tidying the

stock cupboard. He was one of the youngest in the class, and was “fairly happy” .

(int2#92-#126)

At secondary school, Howard enjoyed science, being attracted first to the “wonderful language”, especially in biology: he still enthuses over words that turned him on - prezygopothesis, postzygopothesis, pituitary. This school too was very formal: “they were good solid teachers, it was mostly copying off the board, they did all the experiments and you watched.” Pupils were not actively involved in science, but it was still “more exciting than history, and a lot more exciting than maths!” (int2#130-#183)

Howard moved to a ‘Civic College’ in Oxford in his O level year; did well in Biology, and chose English, botany and zoology for A level: “I loved biology.. so that was two A levels cleared up.” Enthusiastic botany and zoology teachers led visits to research labs, making students feel they were “at the cutting edge”. (int2#191-#199, #225-#229)

6.3.1.1.2 Becoming a teacher

He decided to go into teaching by default rather than vocation - his mother was a teacher, and Howard was “too short to be a policeman”. He chose a ‘Junior Secondary’ course at a college near Manchester, deferring the choice between primary or secondary teaching for as long as possible. He was inspired by a “leading edge” biology lecturer, who, on field trips, taught Howard to see the countryside “through a botanist’s eyes”. (int2#241-#271, #357-#370)

6.3.1.1.3 Teaching

Howard has taught since qualifying in 1970, when “rote learning and text books” was giving way to a child-centred, topic-based approach. He has been at the same school for most of the last fifteen years: a few years ago he spent a year as head of another school, but ran into budget crises and returned to his deputy headship here. (int1#243, int2#277, #378, #402)

He taught some science before the National Curriculum was introduced, and attended local authority science courses. Later he went on a National Curriculum science course,

where he was taught physics “to degree level”, just for the National Curriculum topics, but has never had occasion to refer to the copious course notes, having always been comfortable with what he was doing in the classroom - and indeed at the end of it, he had forgotten everything he had been taught. (int2#380-#402, int4#281-#283)

He recalls a conversation he had, as science co-ordinator, with an OFSTED inspector, who wanted to know why children were growing cress seeds at Y1, Y2, Y3 and Y5. This inspired him to start doing the ‘conditions for growth’ experiments with pansy, lobelia and sunflower seeds as well as cress. (int4#277)

(Note: After the project, Howard continued at the same school, as science co-ordinator and deputy head, under a new head teacher.)

6.3.1.2 Self-image

Howard sees himself as:

- the lynch-pin of Y3 science teaching (int1#171)
- well-informed and cynical (int2#2-#17)
- having a “sort of scientific-type background”, though erring more towards the arts (int2#80-#90)
- someone to whom maths is alien, but who loves language (int2#175)
- unable to comprehend physics, and proud of it (int4#120-#122)
- the most nervous and stressed person on the staff during inspections (int1#233-#235)
- “anti-tick-sheet”, disliking seeing the curriculum reduced to a series of ticks (int4#229)
- “too long in the tooth” for his approach to teaching to be changed by reflection (int5#283-#291, #333-#343).

He describes how his feelings about biology changed as he became captured by the vocabulary, then encountered inspiring teaching at A level and college, showing how closely such feelings about subjects are related to his self-image as a learner. Biology

“was just another subject at school. I enjoyed it because I could do it, and I latched onto it because of the language. I was good at English, good at reading and absolutely useless at maths and physics and chemistry because they were all maths-linked, and of course that had a huge effect on my confidence. . but with biology I could fit that, it clicked.”
(int2#351-#353)

6.3.2 Theories of learning

6.3.2.1 In planning and discussion

6.3.2.1.1 Vocabulary

Though investigations are important, “the rest, basically, is vocabulary”, providing the “building blocks” for later understanding, removing misconceptions and distinguishing scientific from everyday usage. (int1#41, #145, #205-#207)

6.3.2.1.2 Engagement

Engagement leads to learning and understanding, and hence to “good grades”. It is produced by:

- practical involvement in hands-on investigations (teacher demonstration is second best - ‘chalk and talk’ worst)
- the questions asked as an investigation is framed - for example, “Would it work with lobelia?”
- teacher enthusiasm and contact with topical science lead to pupil engagement and ‘good grades’. (int1#43, #69-#75, #85, int2#191-#209)

6.3.2.1.3 Making connections

Howard builds a connection with local geography and history into his plan for the first observed lesson. (int1#29)

Connections with children’s home lives are promoted by the school’s ‘open-door’ policy, which welcomes parents into the classroom. (int1#245)

He believes it is essential to set science topics in meaningful contexts: “that’s why the National Curriculum is set up as it is, because [the topics] all are meaningful”. He tries to help children make connections between their science, other subjects and their lives outside school, but believes that many topics do not lend themselves to this. (int4#160-#166)

6.3.2.1.4 Conceptual change - recapitulation and correction

Howard argues that children’s learning of science recapitulates discovery in a *conceptual* sense - many of their prior conceptions are similar to historical views: but does not follow similar *processes* to discovery. There is insufficient time for them to re-discover the correct conceptions, “so we tell them”. (int1#211-#213, int5#293-#307)

6.3.2.1.5 Developmental processes

He hints at developmental processes in thinking and learning. From “a very early stage”, aged about six, children can identify variables and devise fair tests; but they will need guidance in “thinking laterally, coming up with theories of their own, setting up an investigation” up to the age of thirteen or fourteen, when their thinking will become “quite different”. (int5#293-#307)

6.3.2.2 Deployment of personal theories of learning

6.3.2.2.1 Vocabulary

Howard devotes considerable efforts to teaching technically accurate vocabulary, including ‘variable’ and ‘control’ to Y3 children; and occasionally delights in a word for love of its sound, e.g. “alabaster”. (obs1#34, #506-#508, #512, #606)

6.3.2.2.2 Engaging interest and attention

Howard’s strategy in both observed lessons seems to be to engage the children by entertaining them: his two main tactics are ‘guessing games’ and ‘magic tricks’.

Magic tricks usually involve the sudden production of something unusual, striking in its beauty or strangeness, such as a polished ball of green, banded rock described as alabaster, an ammonite fossil, or a dyed carnation. Occasionally this seems to misfire, in

that children, having come to expect such entertainment, can sometimes mistake the build-up to something quite ordinary for the imminent arrival of a magic trick, and are consequently deflated. (obs1#34-#42, #81, #89, #113-#173, #352, #453, #466, #567, obs2#268-#292, #316)

The guessing games elicit contributions from many children. They start with a question posed by Howard: it is clear that there is some specific answer that he needs to get to. These games are important structural components of lessons, linking between and 'clearing up' bullet points from the National Curriculum and lesson plan. Contributions tend to be passed over if they are not 'en route' to the specific answer. (obs1#26-#34, #69-#81, #141-#151, #370-#398, #398-#424, #466-#475, obs2#37-#64, #230-#247, #268-#290, #294-#314, #316).

He also tries to make sure the children know what they are doing and how it links with what they have done.

6.3.2.2.3 Making connections

Howard connects what he is teaching with children's home lives, prior learning, and general knowledge. The connections seem to emanate from Howard, rather than being elicited from the children. (obs1#34, #42-#49, #51, #171, obs2#247-#251, #316, #366-#374)

6.3.2.2.4 Praise, encouragement

Howard frequently rewards children with praise. The occasions for this seem to be:

- recalling information (obs1#69, #119, #121, #127, #415, #428, obs2#45, #278, #331)
- offering a good explanation (obs1#104-#109, #147, #149, #173, #408, obs2#94, #199, #318)
- volunteering relevant but unsolicited information (obs1#46, #173, #442)
- helping with a demonstration (obs1#139, #157, #163-#165)

- making a good guess or an intelligent answer (obs2#52, #227, #255, #290, #314)
- good written work (obs2#230, #360, #364).

6.3.3 Teaching

6.3.3.1 Images of teaching

Howard's own education presents two contrasting images of teaching:

- those based on his primary and earlier secondary school experience stress formality, 'solidity', and a transmission/demonstration style of teaching (int2#164, #170-#173)
- those based on his A level and college experiences feature enthusiasts doing 'real science', at the cutting edge, straying from the syllabus to pursue interesting topical science, and making trips to visit real scientists or do fieldwork. (int2#191-#193, #357-#359)

Later, two related images came to mind:

- "children sitting at their tables and the teacher off-loading to them"
- "children working at their tables and a teacher going round".

He compares teaching with acting, referring to the teacher's experience, when their "delivery" is good, of seeing "a light behind their eyes" that shows that the children are "taking it on board". (int4#16, #28-#40)

Science teaching *should* differ from the generic model: "children should be doing science experiments in small groups, and the teacher should be facilitating"; but what *does* happen is, the teacher demonstrates and the children watch, because of class sizes, lack of help and resources, and because few topics really "lend themselves" to practical work. However both approaches "are good science teaching". The general structure of a science lesson is thus:

- an 'input' at the beginning, so they understand the concepts and know what to do

- demonstrations, desk work or, occasionally, practical work in groups, whose purpose is to reinforce the input
- plenary discussion. (int4#18-#26, #42-#46)

Trying to stretch a class can lead to poor teaching: “you do a bit too much and you’ve left them: when they come to regurgitate it they’ve got a mishmash of stuff”. (int4#98)

Howard accepts all my suggested metaphors for teaching, and suggests ‘pet images’ of his own: “Messiah” and “Healer”. He makes many references which link the teacher’s role to the stage, some composite of actor, stand-up comedian and conjurer. (int4#52-#76, #90-#108)

The pupils’ job is to:

- make (intra-subject) connections
- “take on board”, “hang on to”, and “regurgitate” science content
- be “interested and enthusiastic”. (int4#78-#88)

Asked to recall his best moments in teaching, Howard “can’t remember a single one”, though he knows he’s had some. Worst moments are similar, though he can characterise these as involving personal embarrassments rather than problems with children’s learning. He cites the first lesson I observed as an example of a good one, but such lessons are ‘the norm’ - were it otherwise, “the job would be impossible!” (int4#90-#108)

6.3.3.2 The role of subject knowledge

Early in the fourth interview, Howard says that subject knowledge is essential: you have to know it in order to teach it, and if you don’t, “you’ve got to get some INSET”. Later he says that the kind of in-service training he had when the National Curriculum came in “isn’t needed.. you don’t have to be a scientist to teach science”.

Most people can pick up the subject knowledge required to teach the KS2 curriculum “pretty quickly”, and most know more than they think they do, making it easier to “mug

it up". Given the option, all teachers in the school preferred to spend the science budget on resources rather than on training to improve content knowledge.

No teacher can know everything: when subject knowledge is challenged in classroom discussion, Howard will offer to find out for them; ask them to find out at home; or direct them to resources in school which will give them the answer. (int4#146-#157, #281-#285)

6.3.3.3 Professional development

Now fifty years old, Howard finds adapting to change increasingly difficult. Professional development, which may be rapid in the earlier years of teaching, has ceased - it is as much as he can do to react to and accommodate externally initiated change. (int5#333-#347)

6.3.3.4 Tensions and constraints

The bureaucratic apparatus - record-keeping and inspection - that has come into existence alongside the curriculum is less welcome and less useful than the curriculum itself, which is "in a way very good", at least in comparison with the literacy and numeracy hours, which are "squashing everything else" into the afternoon. (int2#275-#289, #341-#345, int4#229-#249)

SATs bias teaching towards an emphasis on 'naming of parts', but do not have an undue influence on teaching in Y5. In key stage one, however, "the pressure is enormous", having to do the whole syllabus in five terms, starting with rising fives who need help with all sorts of everyday tasks. The KS1 teachers may be trying to do too much, but the pressure of SATs forces a focus on naming of parts and rote learning. (int4#70-#76, #132-#134)

'Health and Safety' considerations can preclude certain kinds of concrete experience. (int1#71)

6.3.3.5 Reflections on teaching

Howard notes the cyclical swing from “rote learning and textbooks”, to topic-based, child-centred, then “back to the basics” with the National Curriculum and OFSTED: “but if you ever went back to the basics that we had in the sixties.. they’re so boring, the kids would just go bananas.. outside school their whole life style is totally alien to that sort of work.”

Primary teaching is “totally different” from when Howard started teaching, though

Howard’s approach has not changed much. He characterises good teaching as involving:

- watching out for children who are not listening, in order to “bang questions at them, and keep them on their toes all the time”
- making sure that you draw answers to questions out of the less able and ‘special needs’ children
- letting the children “really get hands-on”. (int1#129, #155, int1#183, int5#267-#273, #277-#281)

6.3.4 Primary science

6.3.4.1 Purposes of primary science education

The most fundamental purpose of Howard’s science teaching is to help children develop open-mindedness. He fears the current emphasis on content will produce children unable to think for themselves, though we will not be fully aware of this consequence until A level science results start to decline. (int5#309-#331)

Children also need:

- to understand the tentative and changing nature of scientific knowledge
- to acquire the vocabulary they will need when they start secondary science
- to acquire a way of looking at the world that acknowledges its fascinating and awe-inspiring nature

- to learn to think logically and follow procedures in a disciplined way
- to understand fair testing and variables.

Developing a sceptical approach to assertions and evidence is not part of primary science's brief.

Expectations of pupil progress are enshrined in a series of assessment instruments that are administered as paper-and-pencil tests before the end of each topic. (int1#221, int4#187-#199, #217, #227, #271-#277)

Howard sometimes discusses topical science stories from the media with his class: most recently the search for methane as a sign of life on Mars. He also plans to raise the Russian space programme in a moral tale along the lines of spoiling ships for ha'p'orths of tar. (int4#110-#112)

6.3.4.2 Preferred directions for the development of the curriculum and practice in primary science

At present, science is nearly all demonstration, because of logistical difficulties like limited time, supervision and resources: these all arise from a lack of money.

Given the resources he would look for a technician, investment in resources, and classroom assistants to facilitate independent group working - these would mean a lot more investigative science, and "through that you'd teach the vocabulary." However the priority up to the end of KS2 would still be giving the children a grounding in "the actual words and terminology", so that when they move up to secondary school and "get more into investigation", they will be equipped to take advantage of it. (int3#247, int4#178-#180, #263)

Communication and liaison between schools in the partnership, and between colleagues in the school, could be improved. (int4#128-#144)

Though Howard describes the National Curriculum as tight and dense, the only change he would like would add "the five senses" into key stage two. The curriculum requirements themselves are very modest: teachers over-deliver, perhaps driven by their

knowledge of past SATs papers. The curriculum has a good balance of topics and concepts, content and practical. He shares its objectives. A particular problem with the content is the high proportion which does not “lend itself” to practical work. (int1#171, int4#18-#26, #42-#46, #134, #168-#176, #251-#261)

His emphatic message to anyone reviewing the primary science curriculum is: “Leave it alone. Leave it absolutely the same. Leave it as it is. It’s good.” (int5#351-#359)

6.3.4.3 Concerns

When he approaches a science topic, Howard’s main concerns are:

- “hitting the concepts I’m supposed to”
- making it “a bit whizzo”
- knowing exactly what answers the ‘guessing games’ should lead to
- translating science content into “childspeak”. (int2#404, int4#185)

6.3.5 Science

6.3.5.1 The nature of science

Science is a discipline and a way of looking at the universe, characterised by specificity, precise measurement, and analysis. Its goal is “finding out how things work and fit together”. (int3#16)

Physics, chemistry and biology are the main sub-disciplines. Maths, used extensively by science, is not a science itself. Psychology is a science, since it has theory, hypotheses, experiments, and [replicable] results. Humanities and social sciences are not, because their results “can be misinterpreted too easily”. The curriculum area furthest from science is “the creative side” - art, music, drama - though “it’s difficult to say that science isn’t creative”. (int3#29-#41)

Howard’s immediate reaction to the phrase ‘scientifically proven’ is that it indicates an air of scientificness being created for marketing or propaganda purposes. The basis of belief

Science is demarcated by its procedures, and the absence of an aesthetic element in evaluating its claims. These are not subject to fashion, cultural values or opinion, and are refutable only by better science: in this sense, scientific knowledge is always tentative. We accept it as the best available at the time, knowing that it can change radically in the light of new evidence, which may itself arise from investigating new theoretical speculations. (int3#51-#61, #219-#221)

Our knowledge of the world is a broad view derived from a variety of disciplines or forms of knowledge of equal validity, that differ in their procedures, objects, and interpretations of the world. (int3#63-#65)

Concepts introduced in scientific theories exist in the real world if they can be measured or have been named. Paranormal phenomena are “really tricky!” - even if ghosts and telepathy do not exist in the world, at least the ideas of them exist in people’s minds. (int3#69-#115)

He would expect to find recognisable scientific method in all sciences. Theory arises from experimental conclusions, which can be unexpected. Knowledge is an accumulation of facts and ideas and theories, an over-arching idea. (int3#117-#139)

6.3.5.2 The nature of scientists

Scientists need to be open-minded, generous, selfless, good at raising money, single-minded, and cunning. They have unusual analytic ability and clarity of thought, and are motivated by thirsts for both knowledge and fame. (int3#141-#151)

6.3.5.3 Science and morality

‘Pure science’ is special, in that it is an area where the end of “just finding out” can justify means that would not be acceptable for other ends: “you can do things that are totally immoral to get to the conclusion”. (int3#155-#165)

6.3.5.4 Scientific literacy

Asking why science should matter is like asking ‘Why should Shakespeare matter?’: for a lot of people it does not. It makes no difference to their lives, but they are impoverished by not understanding it. (int3#153)

6.3.5.5 Views of science implicit in planning and discussion

Howard observes that:

- science *is* investigation, its primary purpose is to explain (int1#71, #205)
- science equates directly to independent thought (int5#171)
- experimenters need to have “a good idea” of experimental outcomes in order to get funding for the work. (int2#15-#17)
- all scientific knowledge is tentative and susceptible to radical reconstruction, so all claims must be qualified with ‘Scientists think...’. (int1#213, #219-#221).
- teachers must avoid offending staff, children or parents who have an “extra or different belief” such as a Christian fundamentalism. “You have to say, ‘*Scientists believe* that Darwin had a great idea’. Children need to know that it isn’t fixed, there are no Truths, that’s the message.” (int1#215-#217)
- the surface forms of scientific symbolism and vocabulary can be very attractive, perhaps especially to those who have no understanding of their meaning (int2#175)
- science has everyday application in people’s jobs, technology, and consumer products like their food and clothes. (int5#241)

He also implies that the question at the heart of an investigation does not need to be intrinsically very interesting: it is worthwhile finding out whatever one does not know. Thus science’s job is to exhaustively test every possibility, and to disregard inductive generalisation. (int1#85, #99)

6.3.5.6 Views of science implicit in teaching

Several messages about the nature of science emerge from the observed lessons:

- science finds out things nobody knew before, by doing experiments (obs1#173-#191)
- “the earth was made a long time ago, that’s history.. the rock pokes out of the sea and makes islands, that’s geography.. the rock can absorb water, can contain different materials, that’s science” (obs1#322)
- science poses and answers questions, but tells us nothing about why we should be interested in the questions or the answers (obs1#316, #608)
- what we can’t measure, we can ignore (obs1#127-#173)
- it is unproblematic to generalise from the part to the whole without verification (obs1#566)
- it is possible to generalise from a single instance encountered in a ‘thought experiment’ (obs2#94)
- science and fantasy are mutually exclusive (obs2#106-#108)
- it is acceptable to alter unusual results so that they conform (obs2#194-#195)
- it is acceptable for results tables to lose and confuse the information they ostensibly present (see below)
- it is acceptable to assume that what you expect to be the case, is the case (obs2#223)
- science can be wasteful and pointless (obs2#261)
- good ideas can be applauded and rejected for no apparent reason (obs2#268-#290)
- correctness of vocabulary matters more than quality of ideas (obs2#309-#313).

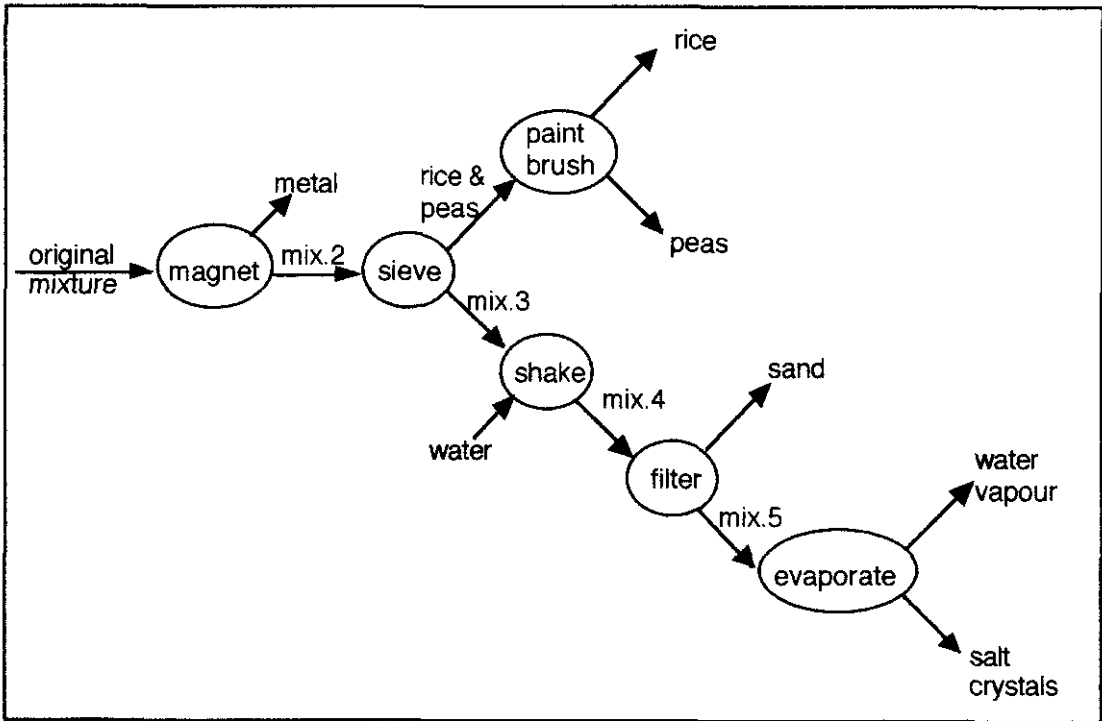
Howard gives a number of scientific explanations beyond the requirements of the curriculum, of such things as the coloration of alabaster, fossilisation, and the formation of soil. (obs1#34, #354-#358, obs1#89)

Results tables

The results table in Observation 2: ‘Separating materials’ loses information, and fudges what could be separate issues: e.g. ‘paintbrush/sieve’ means that the peas and rice were separated from the rest of the mixture by sieve, and from each other by paintbrush. The exemplar results table written on the board by Howard was as follows:

material	method
1. metal	magnet (iron)
2. peas	paintbrush/sieve
3. rice	paintbrush/sieve
4. salt	dissolve
5. sand	filtering

The processes being recorded operate on mixtures and produce mixtures, in general, only occasionally producing a simple individual ingredient, as this materials flow diagram makes clear:



Similarly, individual ingredients are, in general, removed by a series of processes: so for example, sand is produced by using a magnet to get out the metal, sieving to remove peas and rice, adding water and shaking, and filtering.

6.3.5.7 Science outside school

Howard has friends whose husbands are working scientists, a physicist and a geologist. His father-in-law was a “very knowledgeable” amateur astronomer. (int2#416-#426, #434-#436)

He does not actively seek out science stories in the media, but “I just love it when they turn up.. I think it’s fascinating but I don’t read scientific journals and I don’t go out of my way to find scientific stuff and I don’t go to exhibitions.” (int2#428-#438)

He has read ‘The Selfish Gene’ and ‘The Blind Watchmaker’ by Richard Dawkins, and agrees with his theories. He also started but “got bogged down” in ‘A brief history of time’. (int2#440-#450)

6.3.5.8 Reasoning about a real-world issue: head lice

Howard’s beliefs about the behaviour of head lice are:

- They prefer clean hair. Warrant: “that’s what I’ve been told” by trusted authority. Possible explanation: “they can’t get a grip on greasy hair”.
- Cleanliness makes no difference, “they just go for hair”. Warrant: personal experience.
- They prefer long hair to short. No warrant offered, just “I’m pretty sure of that.”
- They prefer girls to boys. Explained by reference to belief 3, and girls tending to have longer hair.
- Social pressures lead to lack of openness about infestations. (int3#167-#189)

6.3.6 Taking part in the project

At the beginning of the first interview Howard clarifies our roles, and throughout he pauses and asks “OK?”, waiting for confirmation that he is telling me the kind of thing I want to hear. (int1#1-#7, #11, #13, #19, #25, #29, #43 etc.)

His remarks to me at break in the first observed lesson suggest that my presence is making him nervous: afterwards he is proud of having taught a good science lesson. (obs1#335, #610)

Other anxieties include:

- suddenly becoming suspicious of my motives, asking quite sharply, “In your research, are you making any connection between religious thought and scientific education?” (int3#99)
- anxiety about his personal performance, suggesting I will find that “people who teach science aren’t particularly scientists, and have a woolly view”. (int3#237)

Positive aspects are:

- he did not know what he thought about some things until he came to talk them through in interview (int2#465)
- having read transcripts of earlier sessions, he finds that at times he answered “with great aplomb”, and would have been happy to talk longer (int3#67).

Though taking part in the project has been interesting, and some of the questions have been thought-provoking, Howard doubts that anything from our conversations will filter through to change the way he teaches or what he says in lessons. He has passed the stage in his career where change of this nature is likely. (int5#283-#291, #333-#343)

Towards the end of the fifth interview he raises the subject of performance-related pay for teachers, and asks me to switch off the tape recorder, consciously going ‘off the record’. (int5#363)

6.3.7 Other Notes

6.3.7.1 Knowledge of and relationships with children

Howard makes several points:

- children's everyday non-scientific understanding includes some "real interesting mistakes": these are elicited at the beginning of each topic, "then we straighten out some of the inaccuracies" (int1#95-#97, #107)
- Y3 children find 'night and day' really hard, and 'the seasons' impossible (int1#107, #159)
- in science, all differentiation is by outcome: even special needs children can absorb and re-gurgitate an incredible amount of information, though they can't write it down (int1#133)
- children "don't think logically, they have this sort of scatter-gun approach, you get a mishmash" (int1#199)
- children find it really hard to understand explanations of why something happens (int1#199)
- children think the dark part of a crescent moon is the shadow of the earth, which is a good hypothesis, "but you can't test it so you just have to say 'No it isn't'" (int1#125-#127).

Howard takes pride in his knowledge of all his class, as individuals: "Parents evening, I never have notes.. when I do a report, it comes straight off the end of my pen because I know the children." (int1#243)

As well as watching, listening and answering questions, several children act as Howard's 'assistants'. He addresses children differently in different contexts: boys who earn praise are addressed as "good boy", "good lad" or "good man"; if they have made a 'mistake' they are addressed as "mate". There is only one usage for girls: "good girl"

when deserving praise. (e.g. obs1#46, #69, #109, #127, #157, #175, #415, obs2#66, #314, #331, #364)

6.3.7.2 Imagery

Howard uses a number of metaphors in relation to his practice, some of them many times:

- his job is to ‘clear up’ curriculum bullet points: in one interview he uses this phrase eleven times in twelve minutes (e.g. int1#15, #39, #43, #47, int5#97).
- children’s prior knowledge needs ‘straightening out’ (e.g.int1#95, #97, #205).
- he talks of ‘banging questions’ at children, ‘drawing out’ ideas, ‘mish-mashes’ and ‘scatter-guns’ (int1#95, #97, #187, #199)
- he refers repeatedly to the idea of ‘precision’, often accompanying his reference with gesture and expression suggesting minute adjustment and squinting at a fine scale (int3#16, #43, #139).

6.3.7.3 Relationship with colleagues

Howard expresses both criticism of and solidarity with colleagues:

- exploring the ‘why’ at the end of an investigation is the most important part; but “very often people stop with the results” and go no further (int1#71)
- it is important to impress on children that the “scientific truths” we are telling them today are tentative and liable to change; but few teachers do this (int1#213)
- he can write a report on a child in fifteen minutes, because he knows the children; others agonise over every word, and spend an hour (int1#243)
- whole-staff sessions looking at progression in science are in principle conducted regularly, though the last one was done two years ago, immediately prior to an inspection (int4#271-#277)
- most teachers know more than they think or say they do (int4#155)

- “all teachers are competent” (int4#281).

6.3.7.4 Irony and conformity

Howard’s dislike of the inspection system is unequivocal. His feelings about the curriculum and associated schemes of work and assessment are less clear: it is sometimes difficult to tell whether he is expressing conformity with their goals, or irony - for example:

- “I write down what is actually in the National Curriculum, so that we don't get lost.. and then [the LEA] have produced a scheme of work, we use this as a bible here” (int1#19-#21)
- “that's actually in the National Curriculum, that you've got to learn how to sieve!” (int1#43).

6.4 Andrew

Andrew is in his mid-forties, with over twenty years of teaching experience. He is the only person in the main study who was also involved in the pilot. He teaches a Y5 class at a middle school in a pleasant suburb of a city in the central south of England, about a mile from the school at which Irene and Keith teach, and three or four miles from Howard’s school. His classroom always has interesting displays, for example some stunning optical illusions; and material relating to an ‘Ancient Egyptians’ topic which includes many hieroglyphs and their translations.

6.4.1 Life history, self-image and values

6.4.1.1 Life history

6.4.1.1.1 School

Andrew grew up in rural Rhodesia (now Zimbabwe). His father was a teacher, civil servant, a part-time farmer and farm insurance agent; and was a keen gardener, very knowledgeable about natural history. (int2#109-#115)

At primary school Andrew remembers the excitement of rare nature walks, and of bringing back interesting finds to study. Also one teacher made a great impression, though only there for two terms. His particular interest was natural history, and he would encourage children to bring in interesting things that they found, and would “build the lesson round them”. (int2#93-#109)

At secondary school, still in Rhodesia, he took a general science option to GCE O level. He has a strong memory of a physics teacher who “related much of what we did to everyday life - for example he would bring in a packet of soap suds and the science would come from that, rather than the other way round or not relating it to everyday experience at all.” These were highlights: much of the science was less engaging; at A level he took English and history. (int2#113-#125)

6.4.1.1.2 Becoming a teacher

He came to England to go to college, taking a teaching certificate at the same Oxfordshire college where his father and grandfather had trained, his ‘third generation’ status making him something of a celebrity. He specialised in English and science. (int2#115-#125)

6.4.1.1.3 Teaching

Andrew entered teaching in the 1970s and has taught continually since, except for two breaks - one of eighteen months, early in his career, for travel and voluntary service; and one in the 1980s, when he was seconded for a year to a local college, to look at primary science and identify good practice. From the outset he had always taught “quite a lot of science”, finding it interesting and enjoyable, and believing children “got a lot out of it”. (int2#125-#131, int4#270-#272)

A recent experience of teaching science to Y6 was marred by SATs and the league tables having too much influence on how it was taught. “We were expected to revise and go over old papers. This is *not what it’s all about*, I don’t think, so I said ‘I’m really not into this, I don’t want anything to do with it.’”, and he has not had a Y6 class since. He dislikes the creeping specialisation that he sees taking place around him, and the

increasing pressure on him to become the school's Y5 science specialist. (int2#125-#131, int4#354-#360)

(Note: At the end of the project Andrew was still a Y5 class teacher, but was teaching science to all but one of the other Y5 classes. So he is almost the Y5 science specialist: his own class are the only Y5s who are taught science by their class teacher.)

6.4.1.2 Self-image

Andrew sees himself as a generalist primary teacher with perhaps slightly more interest in science than in most other subjects, but does not want to be seen as a science specialist. He recently turned down the job of key stage two science co-ordinator, describing himself as “really not interested in that sort of thing”.

He has strong views on what and how he wants to teach in science, and has managed to assert himself to the extent that he can do as he wishes, within the practical constraints of curriculum and timetable. (int1#20-#26)

He sees himself as someone who:

- is normally fairly placid, who doesn't often “bellow” (int4#58)
- is “a good manager and planner and organiser” (int4#62)
- is good at and fond of language, literature and intellectual exercises (int4#244, #276)
- is interested in science outside school (int4#292).

He tries to develop his own professional knowledge, and to keep up with and contribute to educational research. (int2#211-#215, int4#186-#200)

6.4.1.3 Values

Democratic values are manifest in Andrew's relations with pupils; ‘green’ values also surface from time to time. (e.g. obs1#42)

6.4.2 Theories of learning

6.4.2.1 In planning and discussion

6.4.2.1.1 Mutually reinforcing elements

Though discussed below under separate headings, Andrew frequently refers to the inter-relatedness of building up children's self-esteem, engaging their interest and enthusiasm, and connecting science learning with other contexts, and points out that all are needed by all ability levels.

He believes that children's responses to being trusted and given autonomy include enhanced self-esteem, interest and engagement, and that these lead to better learning. Knowledge consists of *inter-related networks* of concepts, relationships, beliefs, values and meanings, which include affective elements, and reflexive elements such as self-image. Learning consists of connecting the new into, and/or adjusting connections or evaluations in, such networks, through action, observation and engagement in discourse. He therefore sets up the bulk of his science teaching so that children can

- choose who they want to work with, if anyone
- pursue their own lines of enquiry
- take as much time as they need having concrete experience
- devise their own tests
- reach their own conclusions.

He provides the minimum amount of scaffolding to enable each of them to get results they can be proud of. (int1#34, int5#124-#128, #150-#158, #172-#233, #497-#519)

These principles can be generalised to other subjects: in history, by visiting museums and handling artefacts; in creative and descriptive writing, connecting with lived experience and attentive perception; in all subjects, taking opportunities to apply skills and knowledge learnt elsewhere. (int5#525-#531)

He justifies his determination to engage his whole class with science by reference to a research paper he read recently which reported that children's attitudes to the various subjects 'harden' surprisingly early, and that attitudes especially to science were likely to be "pretty well formed" by the age of eleven. (int4#186-#200)

6.4.2.1.2 Context, connections and engagement

Andrew believes that a fundamental condition for learning, in all subjects and at all ages, lies in engagement with the task. This is easier to achieve for all ability levels in science than most other subjects, because of the large proportion of practical work. The less "academically inclined" often behave differently, tending to repeat the same task many times over, but "still get a lot from it". (int4#46)

To embed learning tasks in engaging contexts, and help connect what is learnt into children's existing knowledge and experience, he tries to:

- create meaningful links between topics, e.g. moving from 'Earth and space' to materials via a 'space suit design' project
- contextualise tasks so that they become intrinsically meaningful and the children can "enter into the spirit of the thing". (int1#44, int4#332-#338)

This is much more meaningful than just saying, 'Now here are three or four bits of material, do these tests on them, and write a report': it stimulates creativity, imagination, motivation and ownership: the children become so involved that they take on the role of 'consultant scientists'.

Releasing children's imaginations leads to unexpected connections and opportunities: mapping the solar system and galaxy; thinking about distances and times and thus using mathematics with a purpose; discussion of propulsion systems for spacecraft, the practicability of space travel within and beyond the solar system; and cosmological speculation. The interest and enthusiasm generated by such thinking leads the children to involve their parents and stimulates much more connection between home and school, and often leads to parents or specialists coming in to talk to the class. Such connections

with home, parents, the world of work, and science in the large, are invaluable.

(int2#147-#165)

He also uses contextualisation as a strategy for engaging children in their work, making it meaningful and imbued with purpose, in subjects other than science, for example an ‘alien secret agent’ project in English. (int4#255-#268)

Science stories making headlines in the media offer another important way in which school learning can be connected to the children’s broader experience. Andrew is careful to choose the moment when they are most topical and at least some of the children will be aware of them, and to establish some kind of link with the curriculum, not necessarily in science, for example:

- the *Hale-Bopp* comet coincided with the ‘Ancient Egyptians’ topic, and he exploited the fact that its last appearance had been in the Pharaohs’ times
- an article about ‘Silent Spring’ and the on-going decline in songbirds led to the class inviting a local nature conservationist to talk to them. (int4#254)

Engagement is thus a central goal of his approach to teaching; he looks for signs of it in:

- children’s body language;
- their communication - how they respond to and ask questions, and engage with each other;
- whether they speculate or investigate beyond the brief they have been given;
- whether they want to show or tell others what they have been doing. (int4#44)

6.4.2.1.3 Concrete experience and active ‘doing’

Andrew has never been able to manage rote learning himself, and believes that, while some people may learn that way, others do not, and it is anyway inappropriate for children of nine and ten years. His preferred approach would engage and interest through practical work, even when teaching such fact-oriented topics as naming the parts of a flower. (int5#431-#443, #451-#453)

He stresses the importance of letting children gain extensive personal experience of phenomena, citing examples of the hours they can spend ‘playing’ with magnets, and the educative value of becoming part of an electrical circuit, “not with a finger in the mains, but a 1.5 volt battery and a tingle on your tongue”. (int1#68)

He approaches the forces topic through toys. Deconstructing a toy, then getting the children to reconstruct a simplified form, can lead to conflict between their preconceptions and the physical principles involved; to a concrete understanding of those principles when they get their toy working; and thence to a more abstract understanding, at least for some children. (int2#131, #167, #197-#203)

6.4.2.1.4 Knowing and learning: the relationship of new and prior knowledge

Knowledge, skills and understanding are not necessarily unitary and coherent. Children may be able to “link up circuits perfectly, but still not really understand what is going on because they can’t see the principle behind it”. A question arising will create a vacuum that must be filled: children will make up and accept *any* explanation rather than have none, and these pre-conceived ideas can be very resistant to change.

It is rarely a case of new models or explanations simply replacing existing ones; rather of new ideas being fitted into a network or patchwork of a child’s existing ideas, alongside and interwoven with alternative accounts of the same or related phenomena, perhaps in a piecemeal manner. Concrete practical experience is crucially important in helping children sort out this tangle for themselves, re-forming their original patchwork into one which successfully accommodates and appropriately values the new explanation. This process of experience, accommodation and valuing operates at both individual *and group* levels. (int1#70-#76)

Andrew thinks hard about children’s preconceptions, what it means to change or add to them, and why this can be so difficult. Often it is hard to even get them to question their own ‘models’, and when they do take on new ideas they are often fitted in a fragmentary way into and alongside existing ones.

The difficulty of getting them to consider an alternative is “all tied up with self concept, because the knowledge you have and the theories you have is part of you, and to admit that perhaps it’s not quite the right one, is moving quite a way”. In this sense, learning that involves *replacing* preconceptions with the scientific explanation almost *requires* children to lose self-esteem, because it demands they disown part of themselves: their alternative is to retain their preconceived ideas, and accommodate the scientific version alongside for use in specific (e.g. school) contexts.

One strategy for dealing with this is to confront preconceptions with physical experience: but in practice, deciding between a child’s theory and the scientific theory on the basis of empirical evidence is not always cut and dried: “You can see them thinking ‘Yes, well, your theory sounds OK, but *mine* fits in really just as well with the facts as I see them as yours does, so why change?’!”. Thus in some respects the teacher’s job can be seen as one of persuasion alongside preservation of children’s self-esteem, a process much facilitated by leading children to the point where they believe they have thought out for themselves whatever you wanted to teach them. (int2#181-#195, #204-#211, int3#81)

6.4.2.1.5 Cognitive development

Andrew has always been “very taken with Piaget’s theories of child development”, which are borne out by his experiences with children - for example in the “floating and sinking” topic, extensive concrete experience is needed to lay the groundwork for future understanding: the idea of ‘density’ necessitates holding several ideas in mind simultaneously and thus implies ‘formal thinking’. His approach is let the children try out a wide variety of materials in various sizes, and ask them to try to formulate a general rule that will predict how an object will behave, before it is tested. (int4#78-#84)

6.4.2.1.6 Context-bound knowledge, skills and understanding

Andrew has a problem with the notion that knowledge and skills learnt in one context can be readily transferred to and used in another, for example transferring punctuation from grammar exercises to creative writing contexts. Children tend to compartmentalise, and any transfers must be explicitly taught. (int4#234)

6.4.2.2 Deployment of personal theories of learning

6.4.2.2.1 Engagement

As predicted, the children both go beyond and away from their brief into explorations of their own devising, and become immersed in the context provided by the 'space suit design' requirement. (obs1#12, #27, #28-#33)

6.4.2.2.2 Concrete experience

The children have time and freedom to gain extensive personal experience of phenomena and of using equipment. (obs1#14, #27, #28-#33)

6.4.2.2.3 Prior knowledge

Andrew has sharpened up some of the children's expectations in anticipation of their running counter to what actually happens in their tests, and remarks on their (pedagogically valuable) surprise. (obs1#12, #44)

6.4.2.2.4 Children as people: autonomy, confidence, trust, ownership

Having set up the context in previous lessons and reminded them where they are, where they are going, and why, Andrew leaves the class to get on with it, policing the activities to avoid injury and unfair distribution of resources, but maximising the children's autonomy. Those who need extensive concrete experience are given time and space to gain it; those who are curious and pushing ahead conceptually are encouraged to do so, for example by being given access to microscopes in the (fulfilled) hope that these would help them towards explanations of the differences in properties that they had observed. (obs2#10-#141)

Children need to figure things out for themselves. Andrew does not intervene in many cases of things going wrong, recognising mistakes, failures, and messes as integral to children's learning. (obs1#12, #39)

His use of praise to reward good work and build self-esteem is widespread without being indiscriminate, and is directed at individuals, groups, and the whole class (e.g. #24, #26, #37, #42).

Andrew demonstrates trust in his class by turning his back on them for about fifteen minutes, while at least half are doing something close to ‘playing with fire’. At the end of the lesson he is happy to leave one girl to use the microscopes alone, knowing she will do so responsibly. (obs2#65-#100, #140-#142)

6.4.3 Teaching

6.4.3.1 Images of teaching

The essence of teaching is engaging students in their learning, building a creative buzz, interest, motivation, and a sense of purpose. Practical work is the main means to this end in science, and Andrew tries to make sure that *every* science lesson (two, of an hour each, per week) has practical elements. His main criterion for good teaching is that *all* the children in the class should be engaged in their learning: correctness of content and procedure are less important. Good planning and organisation are essential. (int4#33-#44, #62, #396)

Metaphors for the teachers’ role do not spring readily to mind, but emerge in conversation:

- the ‘tailor’, hand-crafting projects to the “needs and abilities” of particular groups of children (int5#255)
- the ‘theatrical director’ or ‘actor’, dramatically creating a context for practical work, helping the children ‘suspend their disbelief’ (int5#156)
- the ‘benign policeman’ in the context of supervising practical work (int4#50-#60, #71-#74).

His best moments in teaching are characterised by evidence of engagement, such as children carrying an investigation through into their home lives, and bringing it back to share their results with the class. On occasions parents or even the whole family come in, and parents who work in science or engineering may talk to the class, or have the class visit their labs or workplaces, connecting the children’s learning with the adult world. (int4#108)

‘Worst’ moments come to mind easily, still emotionally loaded, characterised by a combination of bad planning or preparation, and the presence of multiple distinct ‘audiences’ in relation to whom he would normally occupy distinct and perhaps incompatible positions. (int4#110, #126-#128)

6.4.3.2 The role of subject knowledge

A good basic knowledge of a subject is necessary in order to teach it - difficult when teaching nine or ten subjects, and more difficult the older the students are. He feels that he can “just about manage” at key stage 2, and argues that as a minimum, a teacher should start at GCSE/O level standard in each subject they teach. If they are interested and motivated they will take it on from there, and develop their subject knowledge further. (int4#286-#304)

6.4.3.3 Professional development

Andrew reflects on changes in his approach to planning and teaching over twenty-plus years. He now plans more thoroughly; tries everything out for himself; and is less “adventurous and wide-ranging”. He has become more cynical about the various schools of thought in education, having seen “fashions, ideas and philosophies” come and go with little good evidence for or against them. He has grown less confident that what he is doing is right, or that there is a “best way to teach children”, and his teaching has changed to reflect this. He makes “far more allowances for individual differences”, trying to picture the children in the context of their whole lives, what they will be like as adults; varying pacing, expectation and method to accommodate them; and is “rather more tentative about being dogmatic”. (int5#351-#373)

6.4.3.4 Tensions and constraints

Andrew’s planning is fluid and contingent, being dependent on progress in current work, school arrangements, and how he and his class feel. He has a “fair degree of freedom” to choose what to do, within the confines of the National Curriculum “topic headings”. (int1#18, #20, #26)

There is always a tension between “how much to give to them, and how much to let them figure out for themselves, particularly with such a wide range of abilities”. Dealing with their immediate needs precludes him having as much reflective discussion with the children as he would like. (obs1#12, #51)

He mentions the pervasive fear of exposing children to even the very slightest hypothetical health risk as constraining activities to the point where they become “very bland and unexciting”. (int1#96-#100)

SATs have had a detrimental influence on science throughout key stage two, transmuting its purpose from intrinsic value to investment in future assessment results, and encouraging rote learning, which neither involves nor interests the children: “one goes through the motions but not with much conviction”. He would prefer to use practical work to engage and interest: “getting a flower, opening it up, and looking at it.. you’re bound to have children saying, ‘What’s this bit?’, ‘What’s that bit?’, ‘What does it do?’”, but there is not time to use both approaches throughout the syllabus. (int5#431-#443, #451-#453)

6.4.3.5 Reflections on teaching

What we are is founded on what we believe: what we look for, value and find in life is conditioned by our cultural inheritance, to which education contributes. Andrew hopes his science teaching will shape his pupils in the direction of being curious and sceptical. He argues against memorising facts, which, being “pretty much unconnected with anything else” in the children’s knowledge and experience, will “buzz around” in their minds for a while before losing meaning altogether. (int5#497-#519)

6.4.4 Primary science education

6.4.4.1 Purposes of primary science

The most general purpose of primary science teaching is the satisfaction and development of children’s natural interests in their environment, technology, and many of the content areas and processes of science. As they move into secondary school, the balance will

shift away from developing attitudes, values and autonomy, towards content and process skills. (int4#398-#400, #412-#414)

Another important purpose of science education is that “the public at large” know enough to be confidently sceptical and critical of science-related issues and policy. (int5#477)

Andrew subscribes to Dearden’s account of the desired outcomes of primary education as including:

- personal autonomy - becoming independent learners, learning how to learn
- “essential basic skills - numeracy, literacy”
- higher order skills like I.C.T., using libraries, information retrieval
- subject-specific process skills, such as designing a fair test in science
- “specific scientific content”. (int4#176, #186, #218, #222-#228, #246)

6.4.4.2 Preferred directions for the development of the curriculum and practice in primary science

There are so many areas in the existing curriculum that interest children, that there is “no excuse for them to be bored and turned off”; and it is now much less prescriptive than it used to be. The scheme of work operated by the school is more constricting - the science department has defined what will be taught when, on what appears to Andrew to be an arbitrary basis. He mentions Bruner and the ‘spiral curriculum’ in questioning this, arguing that “anything can be taught at any age.” (int4#42, #346-#352, #360-#362)

Two areas where Andrew would make changes if he could, are improved management of resources, and reversing the creeping subject specialisation currently spreading through primary education. He has no need of ‘traditional’ science laboratory resources, but replacement of the school’s collection of non-magnetic magnets is presently beyond the departmental budget.

For the most part he uses “junk” that he and the children collect; but teaching eight science lessons a week (two each to four classes), all including some practical activity,

requires a lot of junk. This is as much a problem of subject specialisation as of resources: he would prefer to have each class teacher taking their own science, so that they can link it to everything else they do, and to what they know of the children's outside interests, ideally with another teacher acting as subject consultant.

He recognises that both these prescriptions for improvement have cost implications and are unlikely to happen. (int4#382-#388)

6.4.4.3 Concerns

Few topics come up which Andrew has not taught before, so he generally has a tried and tested approach, or perhaps a repertoire of such approaches, to draw on. He may vary his approach for a number of reasons - to try out new ideas, to adapt it to the resources or time available, to adapt it to the particular class he is teaching, or to fit in with contingent constraints or opportunities.

Though he has a considerable stock of "resources" (e.g. boxes of mechanical toys for 'forces'; boxes of pumice stone, wood, etc. for 'floating and sinking'), he is always concerned that he may not have enough, and could do with more. (int4#394-#396)

6.4.5 Science

6.4.5.1 The nature of science

Andrew sees science as playing a part, alongside other areas of learning, in understanding and explaining our lives and experiences. It is demarcated from other areas by its characteristic processes, focused on the material world, which constitute "scientific method". This produces facts and knowledge applicable beyond the context of their discovery, but provisional in that the process is not foolproof. Scientific knowledge increases cumulatively: theories can be "renewed and changed" both in the light of new knowledge and new facts, and as a result of asking better questions or making better interpretations. (int3#19-#23, #29, #113-#115)

Science investigates the reality behind phenomena, which is not necessarily accessible to the senses. He mentions an apparently endless regression - there is always more to find -

and says that the older he gets, the less confident he becomes that he knows what reality and truth are. (int3#29, #105)

He tends to greet claims that something has been ‘scientifically proven’, or that ‘research has shown ...’, with scepticism. In his experience these are most often used to conjure an air of authority for rhetorical purposes, and he admits to having used such phrases himself, to “cover up an area of ignorance” in arguments with colleagues. (int3#63-#75)

A scientific theory is a way of explaining facts and phenomena, how things come to be and why things happen. It consists of a system of ideas put into a framework, and comes from scientists’ thinking about their own and others’ findings, theories and ideas. Theoretical advance often requires new ways of looking at previous findings and theories. (int3#119-#125)

Andrew makes a number of points about how science relates to other disciplines:

- “science could not function without maths”
- “technology is the practical application of science”
- of the curriculum subjects, drama and art are the furthest removed from science, yet science overlaps with all, including these, to some degree
- disciplines in the humanities and social sciences each have their own characteristic processes which are distinct from those of science. (int3#35-#51)

The different disciplines are all equally valid, or perhaps of equal standing; the validity of a knowledge claim is established by the procedures *within* the discipline, and thus validity is a within-discipline rather than an across-disciplines quality. Thinking about science’s knowledge and a ‘shaman’s’ knowledge of rain-forest fungi, he begins by following this implication, arguing that the shaman’s knowledge is equally valid, though reached by different routes for different purposes. On reflection he realises that the shaman’s set of beliefs, though based in part on “many generations of trial and error”, are likely to be integrally bound up with rituals and belief systems, for example sympathetic magic, whose validity he rejects. The parts of the shaman’s knowledge that

are thus accepted as valid seem to be those that are compatible with the causal models of a 'scientific' world view, though they may not be 'known to science'. (int3#93-#103)

6.4.5.2 The nature of scientists

Andrew sees the qualities of a good scientist as:

- integrity, impartiality, tenacity
- having a good knowledge of the field they are working in, and its methods, tools, analysis techniques
- being motivated by pure interest and curiosity. (int3#129-#131)

6.4.5.3 Science and morality

Science and morality are intractably connected: science is the engine of change, informing how we view ourselves and what we are, leading to restructuring of our "moral and value" framework. (int3#137)

The moral messages that Andrew tries to pass on with or embed in his science teaching are:

- that knowledge should not be used for personal gain or to exploit people
- that the criterion by which possible deployment of knowledge is to be evaluated is whether it will, on balance, benefit humanity and "in the broadest sense, the environment".

Application of such simple precepts to real cases is less easy than it might sound. (int3#141-#149)

6.4.5.4 Scientific literacy

Science should matter to everyone because it can help people live fuller lives at various levels, including the kind of everyday balancing acts of eating what is healthy and what you most enjoy. "I know there's a saying, that 'A little learning can be a dangerous thing'.. but I would say, 'A little learning is probably better than no learning at all!'".

The source of the danger in a little learning is that its possessor is unaware of how little it

is: thus a major goal of education for scientific literacy should be for people to learn enough to understand how little they know as individuals, and how little science knows as a whole. (int3#133-#135)

6.4.5.5 Views of science implicit in planning and discussions

Andrew implies that:

- the relationship between science and technology is a continuum, citing the technological flavour of parts of the science curriculum
- all science involves testing some hypothesis by experiment or observation
- scientific knowledge is “what we think we can safely say”
- scientific conclusions are better than ‘random guesses’ because they are supported by empirical evidence. (int1#90-#96, #177, int5#259-#261)

He observes parallels between how children learn science and how scientific knowledge itself is created. Left to themselves, children will spontaneously investigate, observe, and form their own conclusions and theories, “probably half-baked”, but produced by collecting evidence and talking and thinking about it. They thus “make a rule” which becomes their hypothesis, which they test and refine using their own, shared or borrowed ideas, constructing a better, more general rule which may achieve consensus. (int5#489-#495)

On external aspects of science, he criticises the “casualness” of the UK’s approach to GMOs, arguing that individuals need to become increasingly critical of science, which is increasingly in hock to vested interests. (int5#461-#477)

6.4.5.6 Views of science implicit in teaching

Several messages about the nature of science occur:

- science should be conducted in a methodical, orderly, tidy manner (obs1#26)
- if there are several possible explanations for some phenomena, we need to think about them and how we might investigate them further (obs1#44)

- measurement to give quantified results, in standard units, makes results comparable and communicable, and avoids inter-observer differences of interpretation (obs1#57-#59)
- in science we are concerned to establish evidence that is as reliable and complete as possible: hence the need to repeat tests, and to carry out tests on all relevant variables (obs1#26, obs2#18)
- if we do not have the ideal equipment for the tests we want to carry out, we have to think hard, improvise, get the results somehow, accepting a degree of inaccuracy (obs2#20, #40)
- science relies on the personal integrity of scientists (obs2#65-#100).

6.4.5.7 Science outside school

Andrew follows science in the media, including occasionally reading specialist magazines like New Scientist, and is particularly interested in astronomy and environmental issues.

6.4.5.8 Reasoning about a real-world issue: head lice

Andrew does not know whether there is anything in the propositions that head lice prefer clean (to dirty), long (to short), or girls' (to boys') hair. He suspects that the research has not been done, and that there is no definite answer.

He remarks that: "we often act on evidence which really doesn't have much basis in reality, simply because it comes from school handouts, official headed paper, or is said very convincingly". (int3#157-#197)

6.4.6 Taking part in the project

Andrew was the only participant to take part in both the pilot and the main study, and was thus involved with the project for about four years. His comments include:

- he found interview and observation transcripts accurate and interesting (int2#1-#13)

- he has benefited from the opportunity to talk reflectively about his practice, though he describes feeling “totally wrung out” after an interview, from the effort of putting into words things that are usually tacit or implicit (int2#356-#358)
- when he finds himself talking about things he has discussed before, it is impossible to make what he is saying now consistent: he falls back on his “general feelings” on things and relies on consistency with those to make the positions he constructs at various times consistent with each other (int3#23)
- it is easy to listen to and judge others’ views, and imagine what you would have said in their place: to go on the record, “to say what you positively think, verbalise your own ideas”, is hard work (int3#253-#255).

At times he is ‘stumped’ by the generality of the questions, and deals with them by narrowing the scope of his answers to contexts familiar to him (int3#65-#67, #137-#149). At other times he pauses and reflects at length before responding: for example, having talked about how his approach to planning has changed over the years, I asked “Has your approach to teaching itself changed over time?”. Before making a substantive response, he hesitated, then commented that “this is something you don’t really sit down and think about, unless someone directly asks you.” The response that followed seems to be constituted of reflections on his career specifically stimulated by involvement in the project. (int5#361-#365)

He was aware of changes in his thinking about science occurring concurrently with the project, suggesting that our discussions have made him “rather less dogmatic, less sure about what science or any other area of human knowledge can ultimately achieve” (int5#377). At the same time he believes that his views on science teaching have not changed fundamentally: if anything he is now more convinced than ever of long-standing “basic thoughts about teaching science at this level”:

- “they need lots of practical work”

- each child needs to “investigate at their own level”: some are not ready for “more conceptual ideas”, and just need to “mess around.. and whatever you do or say, you cannot stop them!”; others need a more conceptual approach
- it is worth exploring the knowledge they bring with them, not so much to try to change it, as to better enable you as a teacher to help them relate what you are doing to their background experience and knowledge
- children vary in many ways, and a variety of approaches need to be employed.
(int5#424-#431)

Later he adds that he is now “more interested in science education, and indeed, in science and the advances in science” than he was before the project. (int5#455)

He is interested in the fate of the tapes that record our discussions, and seems surprised to learn that, as the basic evidence on which all else is built, they could be spot-checked by anyone needing to validate my work and ensure I am not ‘making it up’. (int5#386-#402)

6.4.7 Other notes

6.4.7.1 Knowledge of and relationships with children

Andrew’s relationship with the children seems to be tolerant, kind, and firm. He gives licences to talk quite loudly and at length, to play with fire, to explore whatever they find interesting, to ask any question and have it answered, and to make and sort out their own messes and mistakes. His rare disciplinary intervention appear to be quiet and respectful, with a friendly edge. (obs1#23, #26, #27, #39)

He observes that:

- most children prefer to work with others of the same sex, though there are always some mixed friendships, and others who prefer to work alone (int5#126-#128)
- children are very aware of fairness in human relations, and are usually able to translate this into the science context, with help from analogies (int1#34)

- some children will always go beyond the brief; some realise that repeating a test several times is likely to give a more reliable result; tests involving fire will be endlessly repeated (int1#38, #100-#102)
- children *always* have their own ideas: “no one ever says ‘I’ve no idea why this works’” (int2#173-#179)
- children vary in interests, academic ability, maturity, home life: some have not yet passed through the stage of just needing concrete experience: others are more interested and curious, with a real need to know, often accompanied by greater patience and persistence, and an ability to plan and check their work - qualities not specific to science, but helpful in it (int4#48, #86-#88)
- some children come into his class having learned how to plan, do, and record an investigation, some do not: the commonest problem is structuring results tables (int5#140)
- there are large disparities in how much children are aware of topical issues, probably related to parents’ backgrounds and how much such things are discussed at home (int5#461).

Andrew feels he has a good idea of what children “can manage, and what they can’t”, though he is “still surprised, amazed sometimes, by what they can do which I thought they couldn’t, and at the other end as well”. By the end of Y5 most of the class are:

- able to evaluate fairness of tests
- beginning to design tests where only one factor is varied
- beginning to understand why having a fair test with a single variable is important
- taking several measurements and averaging, to get a more reliable result
- able to think a lot of this out for themselves. (int5#156-#158)

6.4.7.2 Imagery, routines, scripts

Throughout the interviews, around 25% of what Andrew says is in the form of ‘reported’ or ‘imagined’ speech, thought or action. These seem to lie on a continuum from scripts that are repeated almost verbatim as essential components in the unit of work, through routines for dealing with particular situations if and when they crop up, to images of situations which Andrew can run through, playing any or all of the roles, describing vivid images or ‘video clips’ of experiences that have been or become important, or that exemplify and perhaps ‘encode’ something important. (e.g. int1#26-#32, #66, #70, #90, int2#103, #109, #151, #211, int5#511)

Routines and scripts serving science pedagogy exclusively include:

- ‘sporting’ analogies to explain the idea of fair testing (int1#52-#54)
- specific strategies for addressing commonly occurring unhelpful preconceptions (int1#62-#66)
- knowing in which topics it is appropriate to “stick to the surface” of phenomena (int1#68)
- amusing anecdotes used to illustrate particular unfamiliar terms (int1#86-#88).

Andrew makes conscious use of imagery and imagination in his teaching, when he imagines the children “outside the classroom and in future years”, helping him see them as individuals and make more allowance for individual differences. In this exercise he draws on memories of ex-pupils who have come back to visit, having long left school, whose success in adulthood bears little relation to their qualities as children. (int5#371)

6.4.7.3 Collegial knowledge

Andrew describes recent staffroom debates, observing that the one thing that you can be sure of in such discussions is that on no one point will there ever be complete consensus. (int3#75, #81)

He remarks that teachers are “very often guilty” of under-estimating children’s ability and potential, leading to lowered expectations and under-achievement. (int4#224-#226)

He also recalls how, in a recent in-service training session on the new literacy programme, he found himself among the “old lags” on the back row, sharing a ‘seen it all before’ feeling about the focus on grammar. There was little choice but to comply with the programme: one can only maintain a detached scepticism. (int4#234-#246)

6.5 Linda

Linda is in her mid-thirties. On joining the project she was in her fourth year of teaching, and had a reception/Y1 class in a primary school in a large rural village in north-west England. Lots of lively work was on display in her room - spiders in a huge red web; clocks; autumn leaves on a tree; butterflies; postman, tiger and hungry caterpillar pictures, and a ‘What we wondered about...’ chart:

What we wondered about ...

bulbs, corms and seeds

Do little bulbs make little plants?

Do big bulbs make big plants?

What’s inside the bulbs?

What are those things sticking out the bottom of the bulb?

Are there potatoes inside to make it grow?

Why do they drink from the bottom, not the top?

Does the skin grow with the bulb?

Is there a bulb that grows into a sunflower?

What is the pointed top for?

Linda was direct, warm and friendly from the outset, becoming even more so as we got to know each other. Part-way through the project she moved to a class of Y3/4 children: on the walls and surfaces in this class were two world maps - Mercator and Peters projection; a ‘golden rules’ poster, along the lines of ‘do be gentle; kind and helpful; work hard; look after property; listen to people; be honest’; two solar system charts; a table with pieces of wood, bark, cones, and a bonsai tree; two lemon trees; musical instruments; a collection of prisms, mirrors, lenses; and large paintings of trees, suns

and blue pools - visions of 'The Cressleigh Community Woodland in the next millennium'.

6.5.1 Life history, self-image and values

6.5.1.1 Life history

6.5.1.1.1 School

Linda has happy memories of attending a "tiny little village school", by the church, in a pretty valley on the western edge of the Pennines. Abiding impressions are of very traditional teaching and too much history. Being academically able, she was often left to get on with things alone, and resented the lack of attention. The only science came when a student teacher had the whole class building a scale model of the solar system from papier maché and coat hangers. Linda's job was to make Saturn, and she loved it.

(int2#15, int4#53-#63)

Outside school, from a very early age, "all I ever did was play teachers.. I used to teach all the kids in the street". (int2#27)

At secondary school she enjoyed biology and chemistry, and disliked physics, but took all three to GCSE on the basis of (bad) careers advice, becoming the first girl in the school's history to take physics, and being intimidated and made to feel unwelcome by the physics teacher. She passed biology, just failed chemistry, and was defiantly proud of her 'U' (unclassified) in physics. (int2#27-#33, int4#67-#99)

Having earlier wanted to be a vet, her ambition shifted to graphic design, and she decided not to stay on at school for A levels, but to take a foundation course at Art school, where she had fun but did little work. (int2#27-#33, int4#101-#103)

6.5.1.1.2 Getting a job

In her second term at Art school, she was offered a well-paid job as a ceramic artist with a local pottery, and was pushed into it by her father, who had little time for education.

On starting the job she tried to retain contact with education by enrolling for A level English at night school, but soon felt she was falling behind and gave up. She kept the

job for eleven years, earning “tons of money”, painting figurines, on piecework.

(int2#27-#33, int4#103-#111)

6.5.1.1.3 Night school

During this time she married. Her husband worked in local government, and was always studying for exams, prompting Linda to start a one-year ‘foundation’ evening class in catering - a very positive experience: for the first time in her life she felt like a “leader”, sought out for advice. Her self-esteem grew, and she went to see a “brilliant careers advisor”, who suggested she build a broad-based pyramid of qualifications - first more GCSEs, then A levels, then a degree. In the next year she took and passed maths and chemistry GCSEs, and her interest in science was rekindled by an “absolutely inspirational chemistry teacher”.

She went on to take A levels in English Literature and Biology, finding the latter boring because of a poor teacher’s reliance on hand-outs. She enjoyed the only practical work she did, an investigation of the vitamin C content of Brussels sprouts from different sources - but feels in retrospect that the course was too fact-oriented, and taught her little about the processes of science.

She passed both A levels. During this period her desire to become a teacher had crystallised into a firm decision, overcoming her reluctance to lose the income from the ceramics job. Feeling it was “now or never”, she applied to do a four-year B.A. with parallel Cert. Ed. course, specialising in English and Visual Arts, at a local college.

(int2#27-#33, #73, int4#101-#103, #111-#115)

6.5.1.1.4 Becoming a teacher

She became a mature student in 1990, and “had an absolute ball”. There was a very “exploration-oriented” six-week block of science every year: Linda preferred a more structured approach where learning objectives were set and shared with the children, and debated such points vigorously with her tutors - who have now, she thinks, come round to her view. She feels she has learnt more about teaching science “on the hoof”, by doing it, than she learnt in college, though she still has worries about how to teach ‘AT1’

(Linda uses this, for ‘attainment target 1’, from early National Curriculum documents; it is also known as ‘Sc1’, ‘Science 1’, ‘Experimental and investigative science’, and, in the most recent revision to the curriculum, ‘Scientific enquiry’).

Two fads swept the college towards the end of her training: ‘learning objectives’ and assessment. Something she now values very highly, having worked out over several years how to use it, is concept mapping, which she uses primarily as a formative assessment tool. (int4#115-#117)

6.5.1.1.5 Working as a teacher

In her first school Linda spent one year teaching Y2, then two years with Y6. In Y6 science meant “pouring in facts” in order to get good SATs results. The school was “so rigid” that she stopped doing things which she values highly, like investigations and team presentations. In her current school she has taught reception/Y1, and Y3/Y4. (int2#245)

She has learnt, and continues to learn, a lot from colleagues, especially in ‘Scientific enquiry’, and is only now, in her fifth year of teaching, beginning to feel “really confident in conducting investigations”. She has recently started explicitly teaching ‘scientific enquiry’ skills as part of or prior to investigations in which the children get the chance to use them.

Looking back over her life, Linda says “I’ve had lots and lots of really wonderful experiences, and also lots of negative experiences.. it’s a horrible way to do it, but sometimes you learn more by mistakes”. Teaching is what she always wanted to do, and now “I just adore it, it’s like play time to me”. (int4#119-#127)

(Note: Linda left the school at the end of the year, to move to the south-east, where her husband was starting a new job. She found an interesting job in a new primary school, as only the second or third member of staff, and was looking forward to the challenge: but I think she really felt a wrench at having to leave a school that she loved.)

6.5.1.2 Self-image

Linda sees herself as “still getting there” in terms of learning to teach, and expresses diffidence and self-criticism, feeling especially weak in experimental and investigative science. (int1#28, #32, #183, #273, #315)

English is her first love, and she feels “pretty confident” in maths and design and technology, describing herself as from a “D&T background”. She is “quite confident with electricity”, and during the planning session demonstrates this by examining and rejecting as unsuitable some Nuffield materials. (int1#70, #82, #225-#227)

She describes herself as “the world’s worst digressor” though “a good boss, the organising type”, a necessary attribute for a teacher. (int1#86, int2#27)

6.5.1.3 Values

Linda’s explicit value statements include:

- respect for the planet and nature
- respect for others, ‘doing as you would be done by’ (obs2#125, #206, #372, #390).

6.5.2 Theories of learning

6.5.2.1 In planning and discussion

Linda’s multi-faceted approach is holistic and child-centred. She argues that

- children learn through “lots of different methods”; each needs access to “a variety of means of learning”
- they have to *do* things
- they have to put things into words and engage in discussion
- they have to reflect on what they are learning and doing
- their identities, wills and senses have to be engaged with their learning
- they need to share in “the whole learning process”, knowing what they are going to do, where it fits in, why it’s important they should learn about it

- they need to have practical and intellectual skills and processes modelled for them - to be shown *how*, in a way they can imitate
- what they are learning needs to be set in a context that is meaningful for them, that gives them a reason for doing it
- what they are learning needs to be connected into what they already know and do, within and outside school
- they need relevant concrete experiences and sometimes need to be given explicit concrete models on which their conceptual understanding can be built
- learning involves balancing and blending knowledge, skills and understanding
- valuable learning activities like exploratory play can be easy and fun. (int1#249-#305, int5.1#121, int5.2#60-#62)

Exploring children's prior knowledge, uncertainties and queries has multiple benefits: it stimulates reflection, thinking and curiosity; establishes a context; provides a form of assessment; provides a record of where they started from; and provides a model for a sort of speculative lateral thinking (e.g. int1#251-#255, #281-#287).

She distinguishes between types of knowledge: content that has to be 'input' by the teacher, and thinking and process skills that have to be modelled. She attempts to interlock these so that they move forward "hand in hand" (int2#75, #192-#194).

Though complex, Linda's theories of learning seem to be coherent, consistent and integrated. In the following sections several aspects of them are drawn out for discussion: this is not to suggest that these aspects are separate or separable in Linda's thinking.

6.5.2.1.1 Treating children as people

Treating children with respect, and engaging them in their learning, both imply letting them know what they are doing and why; what is expected of them and what will

constitute good, adequate and poor performance; and afterwards what they have done and are now able to do, and how well they did (int2#164, #253, int4#123)

She thinks that “children have been kept in the dark for years, they’ve not been let into the secret of teaching and of learning, they’ve been expected to just do it.. So many kids go through the whole school day and they don’t know the reason why they do anything!” Parents too represent an almost untapped reservoir of educational resource, but they also “often aren’t let into the big secret of what goes on in school”. (int5.1#117, #197-#205)

6.5.2.1.2 Engagement

She engages children’s will, curiosity and senses, by imbuing tasks with real purpose, making sure children understand what they are meant to be doing, sensitively leading them to raise questions, leaving tantalising elements of mystery in her briefings, and giving extensive opportunities for concrete experience (int1#197, #251-#255, #251-#255, int4#117, #123, obs2#58-#62).

6.5.2.1.3 Making connections

Linda strives to locate the new alongside the familiar, to make it concrete, and connect it into their prior knowledge and experience gained within and outside school, encouraging both children and parents to bridge school and home. (int1#195, #357)

For example she has taught poetry through Space and vice versa; arranged visits to the school by scientists; linked science investigations of light and shadow into D&T and art projects aimed at making Christmas a “Festival of Light”; and encouraged research in children’s gardens. (int2#13-#15, #194-#198, int5.2#58-#62)

She frequently discusses science stories from the media with her class, often initiated by the children, who are “very concerned about the environment.” The most recent topic discussed was climate change and flooding. (int5.1#145-#149)

6.5.2.1.4 Exploratory play

Exploratory play is often enough to produce profound learning experiences, as in the electrical circuits topic: “I’d like them to have time to just not worry about any end product, and just play with wires and batteries and bulbs and buzzers.. when you see a child get a buzzer working, it’s just magic, there’s enough there in itself.” (int1#243-#247, int4#117)

6.5.2.1.5 Modelling

Linda believes that many thinking and science process skills need to be explicitly taught, involving the teacher in ‘modelling’ the processes for the children, and providing concrete models of their end-products - children cannot be expected to work it all out for themselves. Examples of such processes include: designing results tables or useful graphs; choosing equipment; making systematic comparisons; designing a fair test that really answers your question; linking question with conclusion; constructive criticism; and reflecting on your own experience. She is keen to identify the ‘micro-steps’ of progressive skill development that will inch the children up through levels of understanding and ability, and recognises a need to help them reflect on what they are learning as they do it.

An example of a concrete model is on the classroom wall: a display of three pieces of children’s work, write-ups of the same science investigation. Each has been assessed (and moderated) at a different National Curriculum level - 3, 4 and 5; and each is annotated with comments as to why it was placed at that level, providing a model of what *the teacher is looking for, and of the differences between good and poor work.*

She has not been doing this for long, and finds it difficult but successful. (int2#61-#73, #81-#136, #142-#150, #245-#253, int4#123, #127, int5.1#274-#283)

6.5.2.1.6 Reflection

Linda takes care to provide many opportunities for children to reflect on their learning *and how they feel about it* - explicit calls to pause and reflect in the middle of practical sessions; during plenaries; in end-of-day round-ups - believing that it is in this process that links are made or strengthened with existing concepts and queries. (int1#305-#313)

6.5.2.1.7 Creating prior knowledge of concrete analogues

She sees a need for children to have experienced concrete analogues that will be useful in understanding science concepts, so that appropriate prior concepts are available for them to hang more abstract concepts on. (int1#249-305)

6.5.2.1.8 Social and cultural aspects of learning

Linda recognises a distinct scientific culture; helps children to engage in it by adopting a 'scientist' identity, which they find exciting; and values peer interaction in designing, conducting, presenting and evaluating or criticising investigations. There are hints that she sees evolutionary parallels in the class's learning: part of the teacher's role is to encourage prolific production of ideas, especially from the children - a kind of variation; another part of it is for the teacher to keep focused on the learning outcomes that she is seeking for the children - a kind of selection. Together this variation and selection contribute to the social or cultural evolution of the class as a whole, which in part constitutes their learning. (int1#249, int2#245-#253, int5.2#62)

6.5.2.2 Deployment of personal theories of learning

Linda seems to deploy all the elements of personal theory mentioned in the preceding interview, and seems to be employing others.

6.5.2.2.1 Inputs

Linda makes specific 'inputs' of substantive science content and of process-related items of vocabulary (obs2#175, #339-#348, #376-#378).

6.5.2.2.2 Self-esteem and autonomy

Linda takes every opportunity to praise and build up the confidence and positive self-image of the children, individually, in groups and as a whole class, helping every one to "let their light shine"; and to give them scope to exercise autonomy. Examples include:

- praising children for giving a warrant for an opinion (and pointing out that that is what they are doing) (obs2#115)

- praising, taking seriously, and never ‘squashing’ children’s offerings (e.g. obs2#123-#133)
- building children’s self-images as inquisitive, innovative ‘scientists’, and singling out for special praise and reward the highly innovative ‘SEN/lowest literacy’ group (e.g. obs2#125, #330, #378-#390)
- telling the whole class how far their efforts have exceeded her expectations: they have autonomously and spontaneously done what was on the worksheet she had prepared, even though she has not given it out (obs2#330, #375)
- leaving supplies of magnifying glasses, test tubes, etc., lying around, so the children have to put together the need and the solution for themselves (obs2#194-#198)
- leaving it to the children to decide how to record what they are doing for their topic books, explicitly refusing to give a steer on drawing, writing, labelling, presentation (obs2#206).

6.5.2.2.3 Engagement

Engaging children’s identities and imaginations

There was a strong sense throughout of the children playing an intent and serious game of ‘being scientists’, which Linda engineered and encouraged, making sure that everyone experienced success in this role eventually; encouraging them to pursue ideas of their own when they had got there; and using only the children’s suggestions to explore the possible explanations of the phenomena. (obs1#34-#36, #71-#75, #79-#81, #84, #90, #116-#118)

Engaging children’s curiosity

Elements of mystery are used to engage the children’s curiosity: for example she opens the first observed lesson with the question “Has anybody noticed what’s on all the tables?”, then leads the children through a verbal exploration of more or less familiar objects, during which interest in the mystery object, the buzzer, becomes more and more pronounced. This leads into a period of intense exploratory ‘play’, with the perhaps less

than completely understood objective of ‘making a circuit’, in which the suspense builds inexorably over a period of twenty-five minutes, culminating in a tremendously powerful moment when the first buzzer sounds. (obs1#52-#70)

Engaging children’s wills

If the children were driven mostly by curiosity before the sound of the first buzzer stopped them in their tracks, they were driven by unflagging determination to make the noise themselves thereafter (obs1#71-#110).

Engaging children’s senses

The sound accompanying the first completed circuit was arresting. The buzzer also vibrated and tingled on the skin, and Linda encouraged the children to feel it, and think about how they might make a “tickle machine” (obs1#85-#86).

6.5.2.2.4 Making connections, bringing school close to their lives

Linda introduces and prompts for connections in her ‘mostly teacher talk’ interludes - examples include:

- encouraging children’s stories: a boy’s pride in his electronic keyboard; an account of plugs and sockets from the son of an electrician (obs1#34-#36, #116-#118)
- using vivid imagery to connect scary crocodile stories with the name and use of crocodile clips (obs1#50-#52)
- making the children think about the ubiquity, usefulness and dangers of electrical appliances in their lives, which they often take for granted (obs1#112-#123)
- connecting school and home for individuals, and linking the home lives of all the children, by way of the diaries and adventures of Barbie, Dumbo and Teddy (obs1#127)
- connecting their being scientists now with their medium and long-term futures - what they would like for Christmas; what they will be when they grow up (obs1#127).

She also encourages the children to share the connections that occur to them as they go along. These include

- their recent literacy work and ‘Chief Seattle’
- class discussions on sand and memories of beach holidays
- homes, gardens and the surrounding countryside
- the various contexts in which we use the word ‘earth’. (obs2#100, #123-#125, #175, #178, #180-#182)

6.5.2.2.5 Modelling science process thinking

Linda models ways of thinking and reflecting for the children:

- the thought processes of science, e.g. evaluating questions, generating hypotheses, reasoning about empirical evidence (obs1#69, #82)
- divergent thinking and analysis (obs2#100-#125)
- how to think about and reflect on what you are reading (e.g. obs2#156, #175)
- how they might reflect on their experiences of teachers and of learning (e.g. obs2#158, #162).

The second observed lesson as a whole provides a model for a ‘science-like’ process of thinking about what we know, do not know, and want to know; exploring phenomena; and finding ways of answering questions like ‘what is it made of?’ and ‘are there different types?’. (e.g. obs2#218)

6.5.2.2.6 Reflection

Linda encourages and instigates reflection, providing models by making explicit her own reflective processes. She talks about her own fears, thoughts, feelings, excitement; asks open questions of similar aspects of the children’s experiences; and digs deep enough to make clear how much science is normally taken for granted in our everyday life. At the end of the afternoon she uses the ‘handing out of the bags’ ritual to stimulate reflection

on what they have learnt, done, discovered, how they had to persevere, and how they felt about it. (obs1#27, #52, #92-#106, #115-#128)

6.5.2.2.7 Assessing prior knowledge

Linda's 'what do I already know?' and 'what do I wonder?' exercises seem to bring to the surface children's prior knowledge, doubts and confusions, gently and sensitively. It seems to promote reflection on what they do and do not understand, to provide a model for the processes of divergent thinking and analysis, to share understandings and perspectives around the group, and to amplify curiosity. Linda spends the first thirty minutes of the second observed lesson on this process, confirming its importance for her. (obs2#93-#137)

6.5.2.2.8 Creating prior knowledge of concrete analogues

Two days before the electrical circuit lesson, the children spend time playing games designed to give them concrete analogues of the 'circuit' concept. One game uses wooden trains and circular tracks; the other involves passing messages round a circle of children. In the lesson itself, she alludes to these games only tangentially at first. Increasingly explicit links are made as the lesson goes on, specifically to help those who have not yet made a circuit, culminating in the direct comparison of arms with wires, hands with crocodile clips, holding hands with making an electrical connection. (obs1#62, #69, #82)

6.5.2.2.9 Right and wrong

Linda shows that she does not mind if she or the children do not know something: you lose nothing by this, but you do lose "if you're frightened of having a go". She points out, and has pointed out to her, that even teachers make mistakes. (obs2#113, #175, #191)

6.5.3 Teaching

6.5.3.1 Images of teaching

Linda's generic image is of a bright, colourful room; busy children, laughing, talking quietly, even secretly; watched over by a tired teacher. In a good lesson it would be clear that "they know what they're doing", and there would be some concrete activity.

For *science* teaching, the image changes to include whole-class discussion, with children contributing the ideas; and purposeful doing, drawing and writing, possibly as individuals, possibly in groups. In a good lesson the children would have some novel experiences, and there would be "quite a lot of laughing". (int5.1#85-#93)

Linda's favoured metaphor for teaching and learning is that of the teacher as gardener and the children as plants. She stresses the need for strong roots and good soil from the outset, to get strong plants - once a plant becomes "wilted and leggy" it will most likely be a weak plant thenceforth, however well you then treat it. Like varieties of plant, too, children are all different and need different care and nutrients "to thrive and survive". (int5.1#101-#113)

Linda articulated several vivid images of teaching, some bad, some good. Amongst the bad were:

- a primary teacher, "obsessed" with history, who had the class copying out "pages and pages of census information. It was like torture. I remember it so vividly, this board going round, and all trying to keep up with him. Looking back now he was a shocking teacher." (int4#57)
- the frightening physics teacher who victimised the first girl to attempt O level physics in the school's history (int4#83-#85)
- "Mr Hand-out", her A level biology teacher (int4#111)
- an unfortunate final-year student teacher: frequently unprepared, without plan or resources, his only teaching strategy 'teacher talk', he was frightened to let the

children loose on any practical activity, unable to function independently, and apparently constantly physically exhausted. (int2#5, #21, #52, #33, #47-#49)

The good included:

- the young student teacher who had Linda's primary class making model planets, with tremendous enthusiasm and a lot of mess - "Jupiter was just absolutely enormous!"

(int4#55)

- her primary school head teacher's passion for music, and enthralling story-telling

(int4#63)

- an "inspirational chemistry teacher" with an enthusiasm for the periodic table

(int4#107-#111).

The best moments in Linda's own teaching career have been to do with art and drama.

She specifically mentions art workshops, and a role-play technique called 'hot-seating'.

(int5.1#131-#135)

The worst moments come with guilt arising from consciously poor-quality teaching, because of tiredness, or lack of preparation, planning or resources. The number of hours in a day is limited, and teachers have to prioritise: sometimes some things must slip, for example in the face of over-riding pastoral demands. (int5.1#141)

6.5.3.2 The role of subject knowledge

Like all teachers there are times when she is "one night's reading" in front of her teaching, but feels more confident and teaches better when she has sound subject knowledge - she is much happier teaching the human body than forces.

She is incredulous that the government ever went ahead with a curriculum requiring specialist knowledge in ten subjects, and welcomes the recent rationalisation: there is now no need to consider specialist subject teachers in primary schools. Her main concern with regard to subject knowledge is catering for 'gifted' children in Y5-Y6, when special provision may be needed.

Lack of knowledge can be turned to pedagogic advantage: children love it when a teacher says “I don’t know”. Linda’s strategies for dealing with this include: discussing what kind of answer a question might have, and what sort of evidence might help decide; sending children to use the library or I.C.T. to research an issue; asking them to research it at home; and asking family members or outside experts for help. (int5.1#175-#195)

6.5.3.3 Professional development

Linda is purposefully completing a portfolio of experience across the primary age range. Having taught Y2 and Y6 in the past, and reception/Y1 at the start of the project, she moved to Y3 the following year, in a conscious effort to learn about child development at first hand and at all stages.

Knowing she cannot master everything at once, she is also concentrating on each subject discipline in turn. At the start of the project she felt she had dealt with English and maths, and was switching focus to science and D&T. There is a strong sense of her being in control, setting herself challenging but achievable targets. An indication of her progress is that she is now confident enough to expose her lack of knowledge by “driving the science co-ordinator crazy” with endless questions. (int1#32-#34, #70-#82)

6.5.3.4 Tensions and constraints

These arise from:

- the mismatch between the realities of teaching and the discourse that has grown up around the curriculum - for example things described in schemes of work as ‘learning objectives’ often seem more like ‘learning activities’: “this language is so hard now” (int1#295-#301)
- the need to avoid risk, and anything that could be interpreted as risky by parents, LEA, or press (int1#335-#339)
- political correctness amongst colleagues: ‘discovery learning’ is PC, explicit teaching and modelling are not, and though she does them, she cannot help feeling guilty (int2#136, #142-#150)

- integrating process and content in science teaching: on three occasions Linda uses the same “wrestling” metaphor to describe her struggle to come to terms with ‘Scientific enquiry’: the school’s scheme of work has a structured approach to investigations, requiring identification of a question, hypothesis, and one or more predictions, and the most acute ‘wrestling’ arises in trying to fit a very simple statement from the curriculum into this framework, for example the curriculum statement ‘Light cannot pass through some materials, and this leads to the formation of shadows’ becomes something like:

Question: Are there materials that light cannot pass through?

Hypothesis: Light cannot pass through some materials

Prediction: Light cannot pass through cardboard.

Light can pass through glass.

etc.

which seems as obvious to seven-year-olds as it does to Linda, who cannot help wondering whether she is missing something important (int2#81-#126, #198-#241)

- limited time: within the time allocated for science, there is a constant tension between the time required to teach content, that required to teach ‘Scientific enquiry’ skills, and the very time-consuming nature of investigations: each class has to do one science investigation per term, but this is always squeezed by the amount of content “you’ve got to get across” (int2#196, int5.1#369)
- SATs, which lead to a focus on learning facts, especially in Y6 (int4#119).

6.5.3.5 Reflections on teaching

Since Linda started training there has been a shift in focus from activities to learning objectives, and since she started teaching, her approaches to planning and teaching have changed significantly. She has really ‘keyed in’ to learning objectives; and allows the children to have more say, and hence is more flexible in execution of her plans.

(int1#183-#217, int5.2#78)

Her first head teacher insisted on a ‘roundabout’ system, which ran counter to the ‘chalk and talk’ instincts of which Linda had become aware during teaching practice: she felt “incredibly guilty” when the head caught her standing at the blackboard talking to the whole class, and ended up feeling “hopeless and pathetic”.

She describes her standard lesson format now as:

- doing an ‘input’ to the whole class, usually of about fifteen minutes
- breaking up for group work
- doing a plenary to recap and discuss what they have done and learnt

which seems to work and is enjoyable. She also has “lots of weird wonderful whacky afternoons when we just go and chill out and sketch round the school gardens and I pretend I’m doing something tied to the art curriculum”. (int5.1#405)

From the beginning of her training she took to heart the belief that ‘Education is not the filling of a pail, but the lighting of a fire’: her mission as a teacher is to find and ignite the fire within every child. To this end she adopts a deliberate policy of trying to see things from the child’s point of view, imagining what they would like most to do; for every child, finding something (not necessarily academic) that they are “brilliant at”; and helping each to some “little personal target” such as overcoming shyness enough to make a friendship. (int5.1#417-#425, #431)

She observes that:

- it is much easier to transmit factual knowledge than run investigations, especially with the younger children (int1#28)
- the key teaching skill in investigations is being able to ask “the right question at the right time” (int1#28-#30)
- good teaching demands personal investment and autonomy on the part of the teacher, and leads to great pride in the achievements of the pupils, especially the less able (int1#193, obs2#196, #209, #211, #330)

- the overall objective is that the children are confident of the knowledge, skills and understanding they have gained (int1#323-#325).

6.5.3.5.1 Progression

Linda argues that teachers need to be aware of progression at a fine-grained level - where children are coming from, the next small steps, what follows them: and that it takes about five years of teaching to gain this level of familiarity in the three core subjects. She monitors progression using:

- before-and-after assessment of subject knowledge using concept maps or ‘what do I already know/what do I wonder?’ exercises
- formal summative assessment using tests
- “informal formative diagnostic assessment”
- teacher self-assessment: “if 80% of your class didn’t achieve your learning objective, it was probably inappropriate”.

Learning objectives are set for each lesson, in the light of appropriate ‘next steps’, and individual assessments conducted against these objectives. (int5.1#371-#375)

6.5.3.5.2 Planning

Linda’s approach to planning has changed significantly since she started teaching. It used to be “arbitrary” and “airy-fairy”, done not for her own benefit but because someone else demanded it. About two years ago this changed: her planning became more concise and “bullet-pointy”, more realistic, and very useful. The units of the plan are “tiny little chunks” that always give her something achievable to aim for. She is now “totally lost” without her plan, which also functions as a tool for self-assessment and reflection.

The school is moving from individual lesson planning to medium term plans which take the form of a network of linked learning objectives. She is enjoying this sort of planning, feeling that it is both necessary and sufficient to answer the questions: “what have they

got to know? what have they got to do? what have they got to understand? and how do you do it?" (int1#207, int5.1#399-#403)

6.5.3.5.3 Literacy and numeracy hours

Linda welcomes the literacy and numeracy initiatives, which answer questions she has been failing to get answered by head teachers for years, and save teachers hours of work. Like the National Curriculum, they require creative interpretation, or they become dry and boring; but children are being pushed way beyond previous expectations and are thriving on it - this could become a pattern for other subjects. (int3#183-#189, int5.1#403)

6.5.4 Primary science education

6.5.4.1 Purposes of primary science education

In some ways the purposes of teaching science must be defined by the kinds of progression that you look for and work to promote: Linda mentions progression in:

- subject knowledge
- thinking skills, e.g. how to make comparisons
- process skills in general
- understanding, of both content and process.

Linda summarises her views on the purposes of primary science on three occasions during the project:

- in the second interview: producing children who
 - love science
 - are able to ask good questions
 - are confident, active, self-reliant seekers of understanding (int2#297)
- later in the project, when explicitly asked what the purposes are:

- make children more aware of the world they live in
- help children understand how it comes to be the way it is, and why
- help children learn to work co-operatively and reliably on practical tasks
- raise children's environmental awareness
- provide a rational basis for various health and safety rules (int5.1#229-#235)
- in the final session: her objectives for the personal development of the children are to simultaneously:
 - ignite a passionate inquisitiveness
 - build the self-belief required to tackle finding out
 - cultivate a capacity to stand back, compare, reason and reflect. (int5.1#417-#425, #431).

Several of these purposes are also met, in equally valid and equally necessary ways, but from a different perspective, by studying literature.

The purposes of primary science used to differ from those of secondary, in being more holistic and situated, and less exam-oriented. That is now changing, with increasing emphasis on outcomes. (int5.1#229-#235)

6.5.4.2 Directions for the development of the curriculum and practice in primary science

The recent easing of the curriculum's prescriptiveness will make little difference to what is taught or how, but will take the pressure off: "that burden of planning for ten subjects was absolutely crazy.. now, I just feel quite freed up." (int1#72-#84)

Linda is happy with most aspects of the primary science curriculum, on the whole sharing its objectives. Her main criticism is that much of the prescribed content is boring and/or obvious: for example when doing 'Space' (The Earth and beyond), the children

want to learn much more about the solar system, but “the National Curriculum learning objectives are just zero!” (int2#15)

In key stage one there should be more attention to skills, concrete experience, and play, and less content knowledge; overall she would like more emphasis on embedding science in the “real world”, though she acknowledges that this is more a question of how it is taught than what is taught. She likes the QCA scheme of work, and feels that, though it is “ten years too late”, its more widespread use would be beneficial.

Her priorities for improving primary science would be:

- letting it settle down for a few more years, so that teachers can get used to it
- cutting the amount of content taught in the early years
- giving teachers more non-contact time
- having full-time dedicated classroom assistants
- having time and funding for professional development
- having a lab technician looking after science resources for the whole school.

These would maximise the quality of teaching, and the time and effort that could be put into it. (int5.1#207-#219, #251-#255)

Given a term’s sabbatical to improve her own science teaching, Linda would spend the first month in a library, reading an eclectic range of background that she could relate back to the curriculum; and in the process pick some topics that she found particularly interesting, and work on both theoretical and practical aspects of them, with the help of a knowledgeable mentor. (int5.1#165-#171)

6.5.4.3 Concerns

Her concerns when she tackles new science vary. They might include having the time to plan well, and to put together appropriate materials and resources; and the correctness of her subject matter knowledge, though this reduces over time as more areas of the

curriculum are experienced, and is greatly mitigated by team teaching and collegial support. (int5.1#223-#225)

6.5.5 Science

6.5.5.1 The nature of science

Linda distinguishes four ‘aspects’ of science: a bank of knowledge; an exploratory, inquisitive approach to the world; a major subset of the academic world; and a subject that she has to teach (int3#20).

Literacy and numeracy mediate access to science; scientific knowledge and analogous processes are embedded in most other disciplines (int3#24). Science is characterised by process rather than content, where process includes creating theory and “theoretical scientific reasoning”: ‘fair testing’ can be applied anywhere, even in English Literature. Linda includes psychology and psychoanalysis in the ambit of science, commenting that to understand children she turns to the idea of the ‘looking-glass self’ and Lacan, and distinguishing opposing traditions in the social sciences, the “mathematical” and the “holistic”.(int3#26, #31-#35)

Amongst the primary school subjects, Design and Technology is the “most natural bedfellow” of science - science’s goals being “finding out”, D&T’s “making things work”. Maths and geography are next closest, though there is some overlap with all. (int3#39-#45)

The phrase ‘scientifically proven’ immediately suggests the misinterpretation or misuse of science in the media, marketing, or government propaganda. Linda is deeply suspicious of official claims of anything being “scientifically proven or medically proven” to be safe: this scepticism is carried through into family health decisions such as non-participation in children’s vaccination programmes. (int3#47-#51)

Science, to be of value, has to be independent; but is at the same time reliant on funding from government and industry, who are “going to want something back for their funding, so true independence is really very difficult to find”. (int3#53)

In assessing the validity of a claim to scientific knowledge, Linda would:

- check its general plausibility using her own prior knowledge and common sense
- look for a ‘kite mark’ or badge of respectability
- exclude anything with moral, aesthetic or religious elements (int3#55-#63).

Scientific knowledge may not be more valid than other forms of knowledge, but may be more important: for example a cure for Asian flu is more important than a “really wonderful poem”. Science has probably changed the world more than art and literature have, but has had less effect on how people think. (int3#71-#73)

Discussing the ‘reality’ of various ‘theoretical entities’, Linda goes through a series of philosophical positions, from naive realism, through personal constructivism, scepticism, phenomenism, and solipsism, to cultural relativism (int3#75-#89).

Scientific method is pluralistic: there are many methods, but all sharing the common thread of “fairness” (int3#93-#99). Scientific theories attempt to explain the natural world, and flow from an innate human tendency to curiosity and model-building, a need to explain, and a refusal to accept that things just happen to be how they are. They are explanatory models derived from data and imagination. Scientific knowledge is tentative, and not the only valid knowledge. (int3#93-#105)

Progress in science is real and cumulative, and arises from a dialectic between factual and theoretical advance. It is continuous, with occasional “breakthroughs”. Like everyone else, scientists’ world-views are “formed by society”: but scientific change can change world-views. (int3#107-#115)

6.5.5.2 The nature of scientists

In Linda’s view a good scientist will:

- be open
- be questioning

- have a special blend of curiosity and creativity
- have clarity of vision
- be able to move between a holistic and multiple different partial perspectives
- be motivated by a “massive desire” to know, not by money (int3#117-#121).

6.5.5.3 Science and morality

Linda makes three points:

- religion and established moral orders function to control and maintain the status quo; whereas science emancipates and frees people to pursue and create their own understandings and personal moralities (int3#125)
- “fairness” is both a scientific and a moral concept (int3#127)
- science and morality are becoming increasingly intertwined, especially in medicine and genetics (int3#69, #127).

6.5.5.4 Scientific literacy

Science should matter to non-scientists because it helps people to:

- understand and evaluate the reasoning behind policy issues
- be questioning and sceptical (int3#123).

6.5.5.5 Views of science implicit in planning and discussions

Linda comments that:

- science and technology are very closely linked
- there is a personal, quirky element in scientific progress that arises from the uniqueness and individuality of each scientist
- science can be done anywhere, by anyone
- science starts with looking closely and carefully, and shows how interesting and unexpected the ubiquitous and taken-for-granted can be.

Parallels between children's learning of science, and scientists' creation of scientific knowledge, lie in the need to:

- keep trying lots of different ways to think about or do something
- build models
- learn and assimilate while “keeping intact something of yourself”
- keep questioning, and avoid squashing independent ideas. (int1#78, int5.1#413, int5.2#58-#62)

6.5.5.6 Views of science implicit in teaching

Messages about the nature of science given or implied during the lessons include:

- solving a scientific problem involves thinking about it from different angles, imagining what might be, looking hard, trying things out, changing things systematically
- science involves exploratory play, within which one comes to understand the meaning of the goal one has been set, and experiences curiosity, frustration, joy, competitiveness, community, consensus, failure, success, and reflection
- science's usefulness penetrates all corners of ordinary life
- precedence is important and linked to the thrill of discovery
- perseverance is important in scientific success
- science involves close, careful observation
- science demands thinking and doing rather than reading and writing skills
- science involves moving through cycles of open-ended exploration and focused attempts to answer specific questions
- good science is open, methodical, shared and replicable

- if you cannot *see* what is happening, you have to use what you can see, know and guess, to help you to *imagine* what is happening. (obs1#69, #77, #82, #92, #123, #127, obs2#184-#188, #196, #218, #330, #336)

6.5.5.7 Science outside school

Linda is interested in science outside school, following it in the broadcast and printed media, visiting museums and attending science-related events with her family. She is sympathetic to but has never joined environmental pressure groups, and shares her pupils' concerns about environmental issues. (int3#47-#51, int5.1#145-#149)

6.5.5.8 Reasoning about a real-world issue: head lice

Linda has gathered her own "scientific evidence" on head lice. She believes that they are "quite happy whoever they land on", and show no preference for clean hair, girls' hair, or long hair, as folk wisdom and official leaflets maintain. Her warrants include evidence from many and varied heads, though long-term "controlled experiments" would be needed to be sure of the effects of cleanliness, length, and gender. Stigma obscures the truth and fosters both the development of such myths and the desire to hide infestation. The only way to deal with that is to de-stigmatise the problem and counter myth with knowledge, preferably knowledge that the children discover for themselves. (int3#133-#163)

6.5.6 Taking part in the project

6.5.6.1 Discussing the purpose of the project

Early on we discussed the purpose of the project and what it will culminate in: Linda had received the 'briefing note', and read and understood it. (int1#12-#14, #357)

On several occasions during the project we need to clarify how our relationship is to work: for example on our first pass through the planning process she is unsure of her role, and we repeatedly re-negotiate the 'think-aloud' protocol. (int1#199-#207).

6.5.6.2 Stimulated reflection

Linda read the transcripts of the interviews and lesson observations as we went along, and found them “really really good”, leading her to reflect on her practice and review her planning. On a number of occasions she was stimulated to think about things in a new way, for example having said that processes characteristic of science can be applied anywhere, she realised that this was true even in English Literature: simply talking led to reflection that would otherwise not have happened. (int2#37-#47, int3#35, int4#33).

Linda’s thinking about the nature of science and science teaching had changed during and partly as a consequence of the project. The start of the project more or less coincided with feeling that she had mastered English and maths, and switching her ‘professional development focus’ to science teaching: our discussions helped her to reflect on what she was doing and to:

- look closely at “whether children wonder why they’re doing something”
- “focus on how science slots into the curriculum, how the curriculum slots into the world”
- “focus on encouraging children to become [life-long learners, who] want to find out and know things”
- “want children to find their learning meaningful, and relate it to other things, other areas”
- instigate out-of-school science activities involving parents, and practical work that takes place both in school and at home
- re-emphasise connections between science and other subjects.

Similar changes have filtered through into her teaching of other subjects, so for instance she is now involving parents in a similar way in a history project. She has noticed high levels of interest and motivation amongst the children, which have been confirmed by parents’ comments. (int5.1#407-#411, int5.2#80)

Overall, taking part in the project has been “really really interesting, and very illuminating, makes you think and question things.. the minute that you stop questioning how and what you teach, you become a bad teacher”. (int5.1#427-#431)

6.5.6.3 Speaking on the record

Several conversations about the tape recorder suggest that both of us are aware of its presence throughout, and concerned to make sure that all we say is successfully recorded. (int1#1-#8, #275, int5.1#150-#161, #172-#173).

6.5.7 Other notes

6.5.7.1 Knowledge of and relationships with children

It is clear from what Linda says and does that she loves, admires and is proud of the children in her class. Throughout she treats them with gentleness and respect, and deals with potential discipline problems by separating children showing signs of creating them, or by two taps on the table to attract attention, and a quiet reminder of how she expects them to behave. (obs1#65, #129-#130)

Before and after interviews she talks at length about her pupils, observing for example that:

- some of her intellectually ‘brighter’ children find hands-on exploration difficult
 - different pupils are “stars”, showing “real flair” for different subjects
 - the less able are also capable of generating good ideas, given the right medium.
- (obs1#134-#140, int2#168-#170, #215)

Linda describes in detail:

- the progression in ‘Scientific enquiry’ skills between Y3 and Y4
- her considerable experience of teaching children as young as Y1 how to do ‘concept mapping’, which she regularly uses as a means of assessment and for access to prior knowledge

- her policy for grouping - she avoids single-sex groups, explaining the need to recognise the difference in males' and females' approaches to science, literature, and maths
 - children's struggles with language, and her suspension of any consideration of spelling etc., in science
 - the efforts she makes to access and assess their prior knowledge and skills, using concept mapping and 'What I wonder/What I already know about..' exercises.
- (int2#158, int5.1#289-#305)

6.5.7.2 Imagery

Linda appears to be reporting and manipulating images of herself teaching, and of her class's behaviour, as she talks, especially when 'thinking aloud' in planning. For example in the first interview she starts to imagine what the central activity is going to be like, how she's going to introduce it, and how excited the children will be; and then backtracks to focus on what has to come before, in the previous week, by way of laying the groundwork. Having roughed that out in her imagination, she comes back to the central activity, describes how she will set out the equipment and rehearses her briefing of the children. She rolls this image forward until she is seeing the first and then all the children completing the main activity, what those who get there first are going to do while the others catch up, and how they will record what they have done; and finally plays through the dialogue that will constitute the final plenary, when she will ask what they have learned and whether they have answered any of their 'I wonder's. (int1#305-#313)

6.5.7.3 Relations with colleagues

Linda is full of warmth towards and praise for her colleagues, admiring their teaching and "always pinching ideas". Each year group plans as a team, though individual teachers also do their own thing, especially with designing activities, and the science co-ordinator is often consulted for ideas. The school as a whole focuses on particular areas

for development - in the first year of the project the push is on investigative science, generating lively debate amongst the staff. (int1#22-#30)

In planning a particular topic, Linda will consult the teacher two years ahead, who will be the next person to deal with that topic with these children, to see what kinds of expectations she has for what the children will have covered when they get to her. (int1#52, #239, #315).

The school runs an unusual programme of study for science based on 'Science Years A and B'. When the project starts it is year B throughout the school. Year B contains 'green plants as organisms', 'living things and environment', 'variation and classification', and 'electricity', including electrical circuits. Next year will be year A, and the year after that, when Linda's Y1 children are in Y3, year B again. Thus the whole school does electrical circuits in the same half term, which:

- creates a buzz about the topic amongst children and staff
- helps with assembling and evaluating resources
- reduces isolation and increases the chances of good ideas getting around
- helps with external speakers
- raises awareness of how the curriculum fits together, and of progression.

Regular staff meetings look at progression in specific topics. Every class in the school does an investigation on the same general topic in the same half-term, and each teacher contributes examples of what they see as average, below average and above average work from their class, which are 'moderated' by senior staff before the meeting, and graded on a sub-division of National Curriculum levels: so they can all *see* progression, and evidence of different teachers' expectations. (int1#36-#66, int2#51-#61)

Linda relates how much fun she and her year colleagues have in jointly planning their science, generously praising their ability. Of other colleagues she says:

- they are often unclear about the relationship between science and D&T

- she is unsure of their views on the literacy and numeracy hour initiatives. (int2#47-#51, int3#45, #183)

Finally she expresses solidarity with her colleagues, and pride in their achievements. She is frustrated and annoyed by the bad press teachers get, and by the amount of advice they receive that is unwarranted and uncompassionate: “I just wish people would come and see; and there must be lots of schools like this one.. thirty-odd in a class producing stuff like this, it can’t be all bad!” (int3#189)

6.6 Keith

At the time the project began Keith was twenty-six years old, and half-way through his third year of teaching, all in this school, all with Y6 pupils. His class has three science periods per week, each yielding 50 minutes of useful time: Keith teaches two, and the science co-ordinator one. Keith and I knew each other slightly before the project started - I had worked part-time in the school the previous year - and were able to talk with a degree of friendship and familiarity from the outset. He became more discursive as the project went on, he got a better idea of what I was after, and a degree of trust built up.

Throughout the project the room had some well-organised displays - The Victorians; City-scapes; Cottage Industry; ‘The Sheep-Pig’; a maths/measurement display; a ‘Notices’ board; Weather; Creative Mathematics; ‘Do you know..?’ (a science display, with children’s work on skeleton, blood, teeth, the miracle of life, three items on shadow, the heart, muscles, the structure of a flower, bones, sun, earth and moon); plaster of Paris ‘heads’; Lakes ’99 - field trip and canoeing photos; 3-D conic models of the Earth’s surface to its centre; barn owl, dolphin and Monet’s Water Lilies posters; and a ‘hand and grain’ poster with the legend “The earth has enough for everyone’s needs but not for everyone’s greed”.

6.6.1 Life history, self-image and values

6.6.1.1 Life history

6.6.1.1.1 School

Keith grew up in a 'shire county', attending a village primary school, then 'High School' (Y7-Y9) and 'College' (Y10-Y13) in a local town, where he took GCSEs and A levels.

He was at primary school during the 1970s. His memories echo the freedom and autonomy that he experienced, and he repeatedly regrets that he is unable to offer his pupils similar scope today (int2#6, #12, #92). He remembers no taught science content, but a lot of practical work, two examples of which he recounts with great enthusiasm. Both occurred in Y6: in one, he and a friend pursued an investigation of coloured inks mixing in water at different temperatures, far beyond the initial brief. In the other, he noticed and investigated the phenomenon of total internal reflection, achieving what he now knows in retrospect to have been a better understanding of what was happening than his teacher had at the time. Though unable to remember detailed results, he vividly remembers the excitement, and the pride in personal achievement, which he explicitly links to his view of the nature of science: "I'd designed this experiment, and I was so excited!.. you are a part of the design, you're part of how it all comes together.. science is as much a process as it is about results, it's a way of thinking." He refers to these episodes on several occasions, and suggests that they provide a conscious model of the kinds of experience he would ideally like to lead his pupils towards. (int2#10, #18, int4#110-#112)

Keith remembers his 'High School' as being a good, well run school, with a "high calibre intake" and good teachers. During his second year there, he realised that he was beginning to do well in science and maths: his biology and physics teacher stands out for the amount of encouragement he gave, for the way he engaged the whole class and particularly Keith himself in exercises of the imagination something like 'thought experiments', and for the connections he forged between science and "real life". Keith was soon amongst the highest ranked in the class in physics and chemistry, and not far

behind in biology. He began to develop self-confidence and a reputation for asking questions. (int2#38, #50)

Moving to the 'College', he opted for physics and chemistry at GCSE, dropping biology. Despite enjoying science, he had a growing feeling of being "trapped", "labelled the maths and science type", being on a track that was increasingly hard to get off, and would lead inexorably to science A levels and degree. At the beginning of A levels he tried to escape, opting for humanities, but changed his mind because he believed himself to be poor at essay-writing, and ended up back on track, studying maths, physics, chemistry and general studies to A level (int2#38-#42, #50).

Having been precociously independent-minded and inquisitive in primary school, his habit of frequently and persistently questioning his teachers grew as he got older, until his A level maths teacher had to stop him asking questions in order to get through the course. Thus, well before he started teaching, he was experiencing the tension between external constraints of timetable and syllabus, and his internal drive towards engagement with the subject matter on his own terms. (int2#50)

6.6.1.1.2 Going to university

In choosing what to study at university he was looking for something that was scientific, "applied", and involved outdoor work in a "real life context". He chose to read Geomatics (roughly equivalent to land surveying) at Newcastle. The course involved physics, astrophysics, computing, and some "very very hard maths". He enjoyed it and took pride in having done it: but decided not to pursue it as a career. (int2#56-#64, #70)

6.6.1.1.3 A year out

During the final year of his degree Keith considered a career in teaching, but did nothing about it. His "driving motivation" was the church, and he took a year out to do voluntary work with "young people" in south London, through an organisation which recruited graduates to work with Christian groups. He found it enjoyable and challenging, and felt it was something that he was destined or called to do at some later point in his life.

During the year he applied for and was accepted on a PGCE course (int2#74-#78).

6.6.1.1.4 Becoming a teacher

He chose an ‘upper primary’ course, partly because he was worried about his subject knowledge, believing it to be inadequate to teach to A level standard; and partly because he preferred the ‘primary’ approach where he could develop a strong relationship with one class, and see the children through “in every aspect of their education” including non-curriculum areas like behaviour and attitude. (int2#86)

His first teaching practice, at a “tightly regimented”, predominantly Muslim school in inner-city Birmingham, was difficult: he felt on edge and marginalised (int2#88).

His second, at a middle school that used the primary approach up to Y6, was wonderful. He got involved with slightly older children in outdoor pursuits and sports, and his mentor gave him a great deal of freedom to try out his ideas with his Y6 class. He was thus able to set up a science investigation which he talked about in his most animated and enthusiastic manner on several occasions:

- an entire half term was spent on what affects plant growth, using a “primary approach”, uninfluenced by key stage three requirements
- he started with a brainstorming session, but didn't give any answers: the children identified soil, temperature and light as the main variables
- he split the class into six groups, two looking at soil (the moles), two at light (the moths), two at temperature: each was “given a commission” to investigate their variable, planning their work themselves
- groups took over areas of the classroom for their experiments, fed back progress and results to the class, became identified as e.g. the soil experts
- everyone enjoyed it: even those with “behaviour problems” became absorbed and were proud to be called experts in a certain field, and given responsibility.

Keith succeeded in giving the children as authentic an experience of doing science as he could create, feeling it important that “they really understand the *process* of science, and perhaps less the content”. At the end of the year they were still talking about it, and Keith

predicts that “years later, they’ll refer back to something like that, because they had ownership of it”. This episode seems to be an important lynch-pin for his ideas on teaching and learning in science. (int1#116-#130, int2#88-#92, int5#70).

6.6.1.1.5 Working as a Teacher

His preference for the ‘primary’ or child-centred approach was borne out and reinforced by an experience in his first year after qualifying, when he managed to ‘turn round’ a child who had “a very black history”, and by other pastoral experiences which he refers to frequently. These confirmed his beliefs in the importance of the teacher’s pastoral role, and in the education of the whole child. He realises he is bucking what seems to be an inevitable national move towards increasingly inflexible subject timetabling and specialist teaching in primary schools, which runs counter to his professional values, and compromises his autonomy as a teacher. (int2#86-#88, int4#76-#78, #80)

Two other episodes illustrate other pressures that, he hints, may one day drive him from teaching:

Eighteen months ago it all seemed to cave in, it was too much. There’s greater and greater expectations on teachers: just getting the basics to a good standard means that you’ve got to spend huge amounts of time doing paperwork.

A couple of weeks ago there seemed to be a black cloud hovering over most of the staff. Hardly anyone in the staff room because they were all in meetings, and very very tired, worn out. Failure is in a sense not working miracles every day. (int4#90-#92)

(Note: At the end of the school year, Keith left the school, the area, and the teaching profession. He now lives in the north, and works with ‘problem youngsters’, for a Christian organisation in the inner city.)

6.6.1.2 Self-image

Keith sees himself as:

- having been a precocious child in some ways, with better physical insight than his primary school teacher; but also a late developer, of “high average” ability (int2#22, #30)

- having been “really good at” science at school (int2#38)
- “not much cop at essays” (int2#42)
- not one of the “donkeys” who took “rural science” (int2#48)
- not good at biology, where he got his poorest school science marks (int2#48)
- naturally inquisitive and apt to persistently pursue awkward questions, to the discomfiture of his teachers (int2#50)
- able to cope with ‘hard’ maths and physics, as demonstrated during his degree course (int2#64)
- cheerfully lacking in knowledge in geology and biology (int1#40-#44)
- someone who learns best by watching and doing, with guidance, rather than by reading or being told (int4#104)
- flawed as a teacher because he talks too much (int1#64-#66)
- increasingly responsible and autonomous as a teacher, as he gains experience (int1#106-#108)
- challenging established practice, and not afraid to follow through on his challenging ideas (int2#90).
- confident enough in his planning to expose his thinking processes to observation by giving a discursive commentary as he develops his plans, and responding freely to questions on the process (int5#46)
- wary of teaching biological topics (int5#38)
- a person of integrity and honour, who strives to do his duty as he sees it: part of this implies balancing science content with practical work: the focus on content prior to SATs offends his professional conscience, and motivates his push to do more practical work after SATs, when he has the opportunity (int5#120-#122)

- a Christian, deeply involved with the church, the source of the driving motivations in his life; distanced equally from modernist and post-modernist, realist and relativist; familiar with and capable of engaging in philosophical and psychological debates surrounding his religious beliefs (int2#74, int3#22, #30).

6.6.1.3 Values

Throughout Keith stresses the importance of freedom and autonomy. He also comes back several times to the subject of caring for children, and fostering their personal growth; and to the values implied by his strong Christian faith.

6.6.2 Theories of learning

6.6.2.1 In planning and discussion

6.6.2.1.1 Self-esteem and encouragement

Two related themes emerge from Keith's discussion of planning: the importance of developing children's self-esteem, and the need for children to learn to think for themselves. Later he mentions the importance of good marks in encouraging children; and the potential of dialogue and encouragement for turning around even the most hopeless cases. (int1#46-#48, #100, #118-#120, int2#38, #86)

6.6.2.1.2 Autonomy and self-image

Autonomy is central to Keith's thinking about teaching and learning. He cannot give his pupils as much freedom as he had, but aims to give as much as he can, arguing that autonomy leads to a sense of ownership and engagement, in turn leading to better learning and increased self-esteem, enjoyment and personal growth (int2#12, #88-#92, int5#24, #70).

Science investigations in particular are geared to encouraging children to take ownership of a problem area, and to become the class 'experts' in that field. The teacher's role is to provide just enough support to enable them to work autonomously and to succeed in developing a level of expert knowledge, helping them to build 'I can do science' and 'I

can be an expert' into the way they see themselves, and 'releasing' autonomy to them in small incremental steps. (int1#46-#48, #100, #118-#120)

6.6.2.1.3 Making connections

Keith stresses the lengths he goes to in exploring children's existing ideas, meanings and associations at the beginning of a new topic. He normally approaches this by recapping on what they can reconstruct, with help, of what they have previously been taught; or for a completely new topic will ask them to 'do a title page' or draw something showing everything they know about or associate with the topic. (int1#54-#62, #68-#70).

During the topic he tries to connect the science content to real life, contextualising and connecting it to children's experiences, to make what they are learning relevant and useful to them, to make the learning process more interesting and stimulating, and to improve the quality of their learning. (int2#50, #92, int4#108).

6.6.2.1.4 Thought experiments

In science in particular, he stresses the importance of engaging the children in whole-class exercises in imagination akin to thought experiments (int2#50, #92).

6.6.2.1.5 Engagement and agency

A pre-requisite of interested and motivated children is an interested and motivated teacher. Given this, Keith observes that, in science, the pupil's role in learning should be active participant rather than on-looker, team player rather than member of audience. In an ideal project he would devote around 50% of the available time to practical work, the remainder being spent in desk work, teacher talk and whole class discussion. (int2#50, #92, int4#68-#72, int5#36-#44, #114)

Pupils need to understand what they are doing and why, through discussions at the beginning and end of each lesson: between these points they need a variety of practical activities that let them "come at it from different angles. It's the practicals they remember, but the discussions need to happen so it's clear what the objective is and what they've learnt." Keith's definition of what constitutes a practical activity is broad, meaning

anything the children have to do for themselves - library research, integrating information from several sources, hands-on work. Such activities are central to his approach to teaching in all subjects. (int4#50-#56)

6.6.2.1.6 Removing barriers to learning

Keith has experience of the effectiveness of pastoral care and emotional engagement with pupils in addressing behaviour and attitude problems which create a barrier for learning. Overcoming such problems can free a child to enjoy their school life and learning, and can thus be a turning point in their whole life. This gives Keith more professional satisfaction than pupils' academic achievements *per se*. (int4#78, #82)

6.6.2.1.7 Social aspects

Children work in ability groups in investigations. Keith differentiates between groups by task, amount of scaffolding provided, and expectation. Each group has to present and defend its findings: the main source of disagreement between groups is inaccurate measurement, and Keith discusses outliers to encourage reflection on the quality of their work, and prompt groups to check and re-do tests. He explicitly notes the importance of consensus and negotiation in sharing results and theory-building, but dismisses the suggestion that there is a relationship between how scientific knowledge is created and how children learn science. (int5#18, #60, #92, #94, #130)

6.6.2.2 Deployment of personal theories of learning

6.6.2.2.1 Self-esteem and encouragement

Keith's attention to children's developing self-esteem is evident throughout in his positive responses to all input from all children, and his efforts to make use of everyone's offerings, no matter how far off beam they may be. (e.g. obs2#4, #18, #55).

6.6.2.2.2 Autonomy, self-image and engagement

He tries to help the children to learn to think for themselves, to take part in the construction of their learning and to take ownership of it:

- he tries to get all the content that he wants to teach to come from the children in the course of dialogues in which he sets questions and links the children's responses with his amplifications of the concept he is working towards
- he devotes considerable time and energy to making sure the children know what they are going to be studying in science for the next half term, managing the dialogue so that it seems that the children are coming up with ideas of what they want to learn about. (e.g. obs2#3-#18)

6.6.2.2.3 Making connections

Keith makes connections between what he is teaching and the children's prior knowledge and experience, for example:

- their own dental health (obs1#98)
- chewing and digestion (obs1#136-#167)
- football and indigestion (obs1#170)
- babies and baby food (obs1#176-#178)
- a school assembly on 'values': how by working together we can achieve what no-one could achieve alone, drawing an analogy with parts of the body (obs1#182).
- when he is eliciting candidate members of an urban food web, the children seem to be overflowing with animal stories (obs2#138-#176).
- he explicitly connects with earlier science learning, e.g. food chains, and to other diagramming techniques, e.g. spider diagrams (obs2#29-#62).

With the exception of the stories elicited by the urban food web discussion, the connections all seem to emanate from Keith himself rather than from the children.

6.6.3 Teaching

6.6.3.1 Images of teaching

The first image that comes to mind is of knowledge being transmitted from teacher to receptive, passive pupils seated at desks in rows, in a large room with sparse furnishing and decoration. Keith recognises that this is a very partial, very Victorian view: the image may be a composite of memories of his own secondary education, and his present school's science co-ordinator's approach with Y7-Y8. A primary classroom would be more colourful, cluttered and crowded, but still very organised, the proportion of chalk and talk being inversely related to the degree to which the content is amenable to children's active participation.

A good science lesson is characterised by the children clearly understanding what they are doing and why; both doing it and talking about it with their peers; and going away clearly understanding what they have learnt. (int4#30-#50)

At other times in discussions Keith often vividly describes episodes from his own schooling and training experiences, which seem to function as archetypal examples of good teaching (e.g. int2#14, #50, #90).

6.6.3.2 The role of subject knowledge

Keith holds that it is unnecessary for a teacher to have extensive content knowledge specific to the subject of an investigation, giving as examples his limited knowledge of geology and biology, and his strategies for dealing with this. (int1#42-#44, #130)

6.6.3.3 Tensions and constraints

Tensions and constraints from three related sources were mentioned as influencing Keith's planning: school organisation; the scheme of work; and the assessment regime.

The school's scheme of work for science, prepared by the science co-ordinator, is an elaboration of a document from the LEA which is itself based on the National Curriculum. It relieves the teacher of a lot of thinking, but tends to be implemented unreflectively. It contains "a lot of padding", going beyond the requirements of the

curriculum - Keith describes how he recently cut a fifteen-lesson block in the scheme of work down to three lessons, by referring back to the curriculum itself: but the political realities of school organisation mean that he cannot make such wholesale changes to the scheme of work across the board, so there is a “huge amount of content” to get through, much of which Keith believes he can only teach by ‘chalk and talk’. (int1#14-#20, #26-#32, #82-#84, #106-#108, #112, int4#46-#48)

Extra pressure on time in Y6 comes from SATs - one year’s work is done in less than two terms, and four years’ work revised in half a term. Thus the minimal ‘one investigation per term’ that is done, is more rushed than it should be; important elements are left out, such as the final plenary, when groups that have investigated different aspects feed back and discuss their findings with the rest of the class; and there is no opportunity for truly open-ended investigations, or discussion of topical science-related issues. The quantity of learning increases; its quality decreases.

As well as dominating the whole of Y6, SATs have increasing influence lower down the school: “every school in the country teaches to the tests and if it’s not in the test they won’t emphasise it”. Though experimental and investigative science is “given plenty of focus in the National Curriculum”, it forms no part of SATs and so is treated as low priority - thus assessment is subverting the curriculum. Keith can never hope to give his pupils the kind of freedom he had at primary school, and nearly all his lessons depart from his ideals; but once SATs are over, he will have a few weeks to teach science as he thinks it should be taught, and will devote around 50% of the available time to practical work. (int1#108-#110, #120-#124, int2#14, int4#46-#50, #98, int5#36-#44, #78-#86, #114)

Though conscientious and hard-working, Keith is in constant fear of losing control of paperwork and administration. He describes his non-teaching workload for the four weeks up to our fourth discussion:

- three parents evenings

- thirty reports
- planning and taking part in extra SATS coaching, “to get the government’s political level four”
- meetings to plan the implementation of literacy hour; next term’s plan for Y6; next year’s key stage 3 maths; next year’s Y6 programme
- weekly staff meetings
- his own lesson planning
- marking of books (on average thirty a night)
- assessments: every half term, thirty papers in each of Y6 science, English, maths, geography, and Y7 and Y8 maths, i.e. over two hundred papers to mark and assign a level to. (int4#86-#90)

6.6.3.4 Reflections on teaching

Keith favours a ‘primary’ approach, with flexibility in timetabling; emphasises process over content; and places a high value on his autonomy as a teacher. He sees his practice as having changed in a number of ways since he started teaching in 1996:

- his planning has become less creative, and more restricted to simply delivering content (int5#118)
- he has gained confidence, enabling him to plan “better and quicker”, and to push for what he wants in team planning sessions (int5#120)
- he finds teaching less stimulating, and is becoming less reflective, and less hopeful that things will change for the better (int5#124).

He is not comfortable teaching in a “secular school”, with whose “humanistic foundation” his beliefs are incompatible: he would prefer the “God-centred foundation” of a Christian school. Though wary of forcing his views on pupils, he does want to inspire their awe and wonder, and finds himself communicating his disagreement with the view that “what we are observing in science is a complete fluke”. (int5#132)

Commenting on W. B. Yeats' aphorism that 'education is not the filling of a pail but the lighting of the fire', he complains that most the National Curriculum is filling pails: lighting fires is not in the curriculum, but good teachers will still do it. (int5#134-#136).

Keith distinguishes 'investigations' from 'experiments'. In both the children have to make observations and record results, but investigations are 'holistic': the children work autonomously, planning the investigation and evaluating the results. He distinguishes three degrees of freedom, used to differentiate investigations for different ability levels:

- children choose for themselves which hypothesis to investigate, and take it from there
- children are directed to a hypothesis that the teacher thinks is appropriate for them, and then are free to investigate it as they wish
- children are directed to a hypothesis and to the equipment to use, and are left to devise the method for themselves. (int1#72-#80, #86-#96, int5#58)

6.6.4 Primary science

6.6.4.1 Purposes of primary science teaching

Keith groups the purposes of primary science into two classes: "a pragmatic side and a heart side".

On the pragmatic side is passing on what humanity has already learnt, a simplified form of the current state of understanding in science, to avoid "re-inventing the wheel" and enable pupils "to better use resources they might come across in later life".

"At the heart of all of it" is helping children to appreciate and marvel at "the patterns and order that there is in creation". (int4#116)

6.6.4.2 Preferred directions for the development of the curriculum and practice in primary science

Keith's main criticisms of the curriculum are that there is too much content, and that too much of the content is not amenable to being taught through practical work and investigations - though when he looked at what the curriculum itself specified, rather

than assuming that whatever is in the scheme of work is required by the curriculum, he was surprised to find that its requirements were relatively modest compared to the demands of the scheme of work. (int1#110)

His suggestions for improving primary science teaching are:

- reducing the administrative burden on teachers
- more open-ended investigation, less recipe-following
- more informal verbal feedback and formative assessment of practical work
- better quality resources, designed by teachers, built to work
- a regular full-time teaching assistant attached to each teacher, to help with preparing resources, assessment, bureaucracy, managing practical work, special projects
- a concerted effort to reform assessment, to make it less oppressive for children, teachers and schools.

Of these he seems to care most about making assessment less oppressive and giving more opportunities for open-ended investigations. (int4#110-#112)

6.6.5 Science

6.6.5.1 The nature of science

Science looks at the mechanics of how things work, natural or man-made, to answer the ‘what’ and ‘how’ questions. Other disciplines ask other questions of the world: ‘why’ is the preserve of moral enquiry, including ‘why did a species develop as it did?’, where science can only address “the nuts and bolts of what happens on the surface” (int3#18, #84).

Subject boundaries are artificial: scientific elements crop up in nearly all disciplines, and are characterised by the harnessing of “rational thought and observation” to provide mechanistic explanations. Technology also concerns itself with mechanism, but to pragmatic rather than explanatory ends. Art and literature seek explanations in terms of intentions, and the communication and stimulation of feelings and sense impressions.

One general scientific method is common to all science, whether experimental or historical: essentially repeatability, verification through testing of predictions, and fairness in research design. The criteria of demarcation for science are method, replicability and predictive power. (int3#60-#72, #128-#132)

The notion of scientific proof is not problematical when applied in contexts where warrants can be found in personal experience: but “at the other end of the scale” scientists are prone to try to “build a framework” which leads them to extrapolate their ideas “into a realm of faith” - for example Darwinian evolution.

Theoretical entities are not ‘real things’ but elements in theoretical and often mathematical models encapsulating our best available description or mechanistic explanation of the phenomenal or real world - the history of science shows that these theories and entities change over time and so must be part of our descriptions and not part of the real world. (int3#90-#124):

Reliable accumulation of facts, and development of theories from which testable predictions can be generated, contribute to “the most powerful thing.. a methodology which has integrity, and informs and builds up a reliable set of knowledge, explaining what’s already there, and by a methodical approach helps us to predict what is about to happen.. and when it does happen, then that I say is an increase in knowledge”. (int3#134, #138-#140, #154)

Keith maintains that our world view sets limits on what science can tell us. He contrasts a bleak ‘heat death’ view of the future with a modernist world view where things will gradually improve, and contrasts each of these with Muslim and Christian world views, arguing that “what science will tell you is limited to the extent that your world view corresponds to a scientific modernist world view”.

Most people hold several things in tension: what personal experience has taught them; what they have learnt from science and similar learned sources; and what they derive from their faith or religious beliefs. His own world view is Christian, to which science makes a limited contribution, in explaining ‘observables’ rather than underlying reality.

He is vigorously anti-relativist, holding that there are right and wrong answers to moral and other questions, and that what is true, is true for everyone.

Science is not in itself adequate to give a “full world view”, both because it is unable to offer an account of the brilliant and intriguing patterns in mathematics and nature, and because it is constantly evolving. When different forms of knowledge appear to be in contradiction, *absolute* standards of truth and morality can be applied. (int3#32-#70, #104).

6.6.5.2 The nature of scientists

Keith distinguishes science from scientists, the former ‘pure’ and untainted by ‘motives’, the latter having personal motivations and ‘hidden agendas’ which define the kinds of evidence that they are prepared to look at. He uses his knowledge of children to understand this: “Because they think they know what’s going to happen, they limit their search to a certain area: I don’t think that changes as you get older”.

He recognises the inevitability of this, arguing that a good scientist must be methodical, have a degree of open-mindedness, and a solid foundation of established knowledge. It is possible to be too open-minded - “you lose all perspective without a framework.. every discovery will change everything”. He hints at both empirical and coherence ‘truth’ criteria, and calls for absolute moral values as a desirable quality for everyone, scientists included.

His comments are self-confessedly cynical: he sees thirst for knowledge sitting alongside thirst for power; and the ability to predict events alongside the ability to control and exploit them. (int3#100-#102, #156-#160)

6.6.5.3 Science and morality

Either your morality can inform your science, or your science can inform your morality, but not both: and scientific knowledge, being liable to change, is unsuitable as a foundation for moral values. Thus he bases his own morality on “an absolute standard”, which is “not at all informed” by his scientific knowledge, while accepting that for many

people the reverse applies. Faith is a better candidate for an absolute standard *because* it is irrational, and cannot be explained or proven.

His friends include scientists and non-scientists, Christians and non-Christians. For some of them, abortion is an issue that science can inform, for others it is not: the split is between Christians and non-Christians rather than between scientists and non-scientists. He concludes that we all draw our morality from our world view, and that in this, scientists vary as much as anyone. For the scientist as for anyone else, only conscience can be their guide. (int3#164-#168)

6.6.5.4 Science and the public

Keith questions the distinction between scientists and non-scientists, arguing that anyone with a ‘complete world view’ should be concerned with gaining a broad scientific understanding as part of that world view, and that this need is as great for those earning a living from doing science as for anyone else.

The public are becoming more critical of scientific and technological developments, and perhaps more confident of their own value systems and more aware that their values are not necessarily shared by those pushing new technologies. This shift is reflected in this generation of “post-modern” children, who do not look at science as “the great hope of the future”, but question both its integrity and what it tells us.

Science is becoming less isolated from moral concerns, though this is not a change in what science is but in how it is perceived by the public. The GM foods debate would not have happened ten years earlier, when the public would have been enthusiastically receptive of any developments with the imprimatur of science: the source of the current unease about GM is people’s feeling that there is something morally and spiritually wrong with it, something to which its proponents are morally blind. In his own case this unease is also fuelled by doubts about scientific values and validity. (int3#22-#26, #94-#98, #160-#162)

6.6.5.5 Views of science implicit in planning and discussions

Keith's comments imply a pragmatic view of method: it is not a question of right or wrong, but whether it leads to a "sensible result at the end"; and it is not always possible to plan investigations - often it is a case of trying different things until something works. (int1#100-#120).

Science is a process, a way of thinking, and hence a human activity as much as it is a body of knowledge. The nature of science becomes apparent through practical work. Open-ended investigations show children:

- how scientific knowledge is created
- that they can create it themselves
- that results are constructed by action: "they don't just appear out of nowhere"
- "that consistent conclusions with evidence build theories and theories build what people then accept to be facts". (int2#18, int5#72, #90)

He explicitly notes the importance of consensus and negotiation in sharing results and theory-building, and the theory-dependence of facts; but dismisses the suggestion that there is a relationship between how scientific knowledge is created and how children learn science as being ideologically motivated, emanating from supporters of 'discovery learning'. (int5#130)

He sees the rationalist or scientific world-view as holding that "what we are observing in science is a complete fluke", by contrast with a Christian view of purposeful creation; and says that he communicates this view of science, and his disagreement with it, to his pupils. (int5#126-#132)

6.6.5.6 Views of science implicit in teaching

Several messages about the nature of science and scientific method seem to be implicit in what Keith says in the observed lessons:

- the first stage of a scientific investigation is exploratory, involving looking closely, counting, classifying and mapping (obs1#84)
- being scientific implies using more “accurate” or precise or just different vocabulary, using words in special ways that can easily trip up the unwary (obs1#103-#106, #170-#174, #obs2#4-#18, #48-#51)
- investigation can be an iterative process: if the first round of observation leads to unclear or confused classification schema, we can pick out some promising characteristic and do more observations, focusing on that characteristic (obs1#108)
- we can ignore what we believe to be extraneous detail in developing our descriptions and classification schemes (obs1#120)
- we should develop a complete and satisfactory description and classification scheme before moving systematically on to developing functional explanations (obs1#134)
- in science we use a multiplicity of different modelling techniques for different purposes (obs2#4-#18)
- in science we sometimes have to guess, to fudge, to make assumptions, in order to make progress (obs2#100-#112, #113-#120)
- we have to be selective, to generalise and to abstract: we can’t include all the details (obs2#136-#138).

6.6.5.7 Science outside school

Keith is interested in science outside school, though his interest does not take him beyond the broadcast media. He is indifferent to environmentalism. The main arena in which he encounters science outside school seems to be in debates around science and religion, with his friends in the church. (int3#164-#168, int5#126-#132)

6.6.6 Taking part in the project.

Keith’s reaction to taking part in the project is generally positive and encouraging. It has helped him to think about usually implicit aspects of teaching and learning that he would

like his pupils to reflect on. He is aware that we have talked about some things several times from several points of view, and acknowledges the possibility of self-contradiction; but has found the discussions interesting and challenging, particularly the planning sessions when he was ‘thinking aloud’. (int3#20, #178, int5#18, #138-#144)

His comments suggest that he is aware of his words being recorded, transcribed, and becoming a source of data in my research; and that by implication his role is in some sense both that of speaking for himself as a teacher, and that of speaking as one of the small number of representatives of the teaching profession on the project. He sees my role as “probing around in his thinking”. (int1#1-#18)

He does not think that his views on the nature of science have changed during the project: they were already well-formed at the outset, having been discussed with friends and thought about at length. (int5#126-#132)

6.6.7 Other notes

6.6.7.1 Knowledge of and relationships with children

Keith makes the following points about children:

- teacher-pupil interaction and teacher talk “turns off” a minority of children, who gain little from it; but most children benefit (int1#64-#66)
- in investigations it is important to stress that the conclusion is the answer to a question, because “quite often they conclude something that is completely irrelevant to the hypothesis” (int1#92)
- investigations give children opportunities to become ‘experts’ in something, and they become absorbed and proud: behavioural problems are minimal (int1#120-#128)
- children “want to be doing rather than listening” (int1#146)
- what children find hardest about independent investigation are long-term planning, and reaching meaningful conclusions, that explain *why* they got their results (int5#72).

Keith seems to have no serious discipline problems with the class, setting the tone from the outset with an ordered and quiet registration, and a simple but effective ‘no place to hide’ approach to gathering in children’s work. He responds warmly to all children’s input, encourages the quieter children to contribute, provides a ‘soft landing’ for completely wrong answers, knows who he can rely on for a ‘good’ answer when he needs to move things on, and can tolerate ‘jokes’. (obs1#3, #55, #128-#132, #170, #180, #191, int5#8, #22)

6.6.7.2 Imagery

Keith often seems to be describing vivid images of remembered episodes, for example when describing two primary school experiences of doing science: “Those two things I saw very clearly, I can picture where I was in the room, and all the rest of it, I can picture it all”. Such images also seem to occur for examples of good teaching, as in his description of the physics teacher who orchestrated the whole-class discourse about hot and cold air and sliding doors, and of his mentor on his second teaching practice. (int2#14, #50, #90)

7. Survey results

7.1 Introduction

As described in an earlier chapter, the pilot study suggested, amongst other things, that:

- i] some primary teachers are sufficiently comfortable with teaching science that they have well-warranted views on:
 - the content and operation of the curriculum
 - how their own practice could be improved
 - how practice in primary science in general could be improved
 - the purposes of teaching science in primary schools
 - the importance of the teacher's subject knowledge
 - discussion of topical science issues in the classroom
 - the nature of science and scientists.
- ii] some teachers have:
 - 'secret gardens' of science content, beyond the curriculum, that they would like to (or do) teach
 - a range of cognitive and pedagogic concerns about science teaching
 - a range of strategies for coping with weaker areas of subject knowledge
- iii] a teacher's views may provide indications of how science teaching has been accommodated into their professional self-image.

The methodology and research design chapter describes how views such as the above were to some extent made accessible by survey instrument. The intention was to use

these data to answer the following questions, which will in turn contribute to answers to the research questions themselves:

- How do primary class teachers feel about science in their own education, and outside school?
- How do they rank science in relation to the other subjects they have to teach, in terms of their self-perceptions of competence to teach them?
- How do they perceive the nature of science?
- What do they perceive to be the purposes of primary science education?
- How important a role do they think subject knowledge plays in primary science teaching?
- How would they prefer to see the curriculum, and practice, developing?
- How would they improve their own science teaching?
- What are their main concerns in relation to science teaching?
- Do any of these appear to be related to each other, or to background variables like age, years of experience, gender, their own science education, contact with science outside school, etc.?

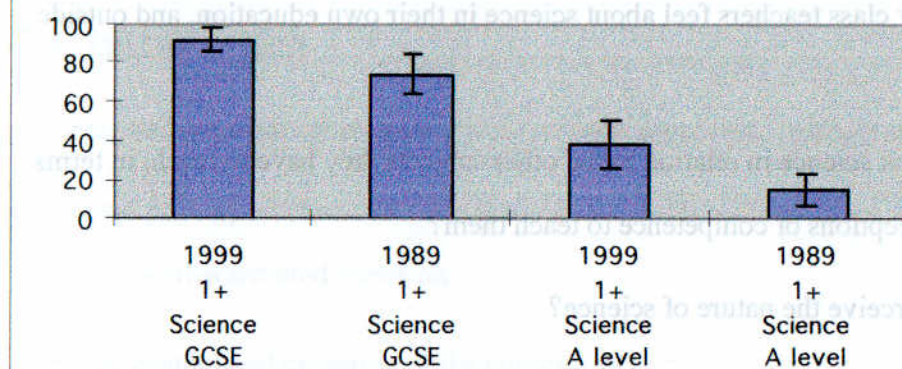
7.2 Conclusions from survey

This section presents the main conclusions drawn from the survey data. Detailed back-up data supporting all conclusions is available on request.

7.2.1 Teachers' own science education

93% of the sample remember doing some science at primary school themselves – 57% nature study only. They appear to be, on average, better qualified in science than primary teachers were a decade earlier (de Boo 1989):

School science courses taken by primary teachers - 1999 and 1989 samples compared



[Note: unless otherwise specified, error bars on charts show 95% confidence limits - see appendix for details.]

Several questions probed how respondents remembered feeling about science when at school: factor analysis was carried out on these. In relation to this and other groups of variables subjected to factor analysis, principal components analysis was used with various combinations of method, including:

- both correlation and co-variance matrices
- extraction of Eigen-values greater than 1.0 to 1.3 times the mean
- both unrotated and Varimax rotation of factors
- various ways of dealing with missing values (stepwise, pairwise, substitution with mean, and default)
- stepwise elimination of variables loading approximately evenly across several factors.

Only factors that emerged as stable across all combinations of methods, and as significant (for $N=61$; $p < .05$; with factor loadings of > 0.7 : Hair et al., 1995, p385), are reported.

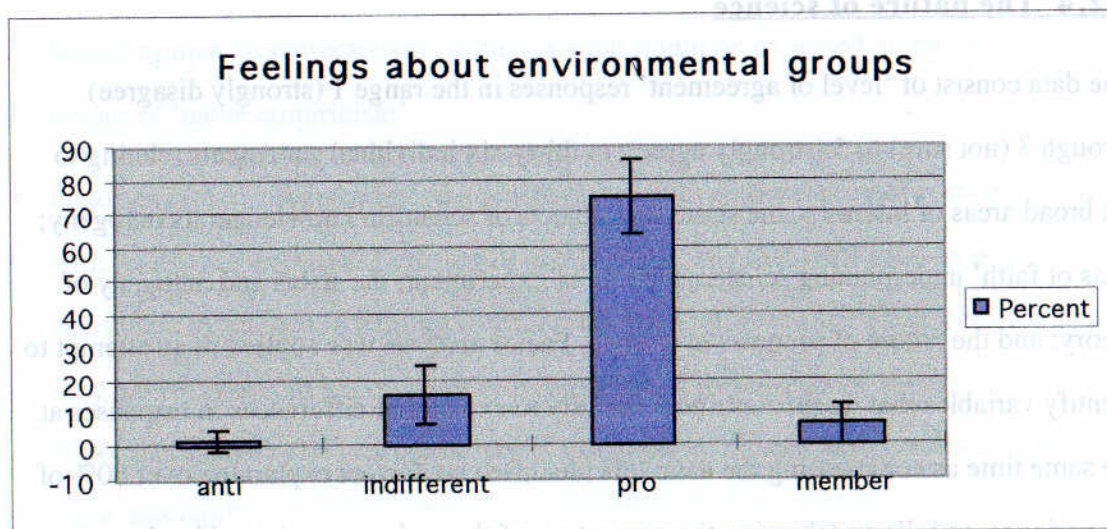
In this instance the following two factors were identified, together explaining some 68% of the variance:

- factor 1, explaining 45%: ‘enthusiasm for science’ - not daunted by science, but interested and confident of being able to do it: the sample is skewed in favour of this factor.
- factor 2, explaining 23%: ‘distanced from science’ - it is not a subject for girls, not ‘cool’; perhaps indicating conformity with a classroom culture hostile to science: approximately normal distribution, with some outliers scoring very highly on this factor.

It is important to bear in mind that such factors cannot be thought of as ‘types of person’: rather they identify more or less independent variables, so for example an individual person could score highly on both ‘enthusiasm for’ and ‘distance from’ science, if they looked back on it as something that they could do and found interesting, but at the same time remembered feeling that it was not ‘cool’ to be good at it.

7.2.2 Interest in science outside school

80% take an interest in science outside school, and over 75% are in favour of environmental groups like Greenpeace and Friends of the Earth.



7.2.3 Rankings of subjects by level of comfort in teaching them

Teachers’ rankings of subjects by their perceived competence to teach them changed significantly in the two or three years following the introduction of the National

Curriculum , but seem to have changed little since. This survey found science to be now ranked 4th, behind English, maths and history, and ahead of geography, art, D&T, ICT, PE and music.

	1999 ranking	1991 ranking (Bennett et al 1992)	1989 ranking (Wragg et al 1989)
English	1	1	1
Maths	2	2	2
History	3	5	3
Science	4	3	8
Geography	5	7	4
Art	6	4	5
ICT	7	n/a	n/a
PE	8	6	6
D&T	9	10	10
Music	10	9	9

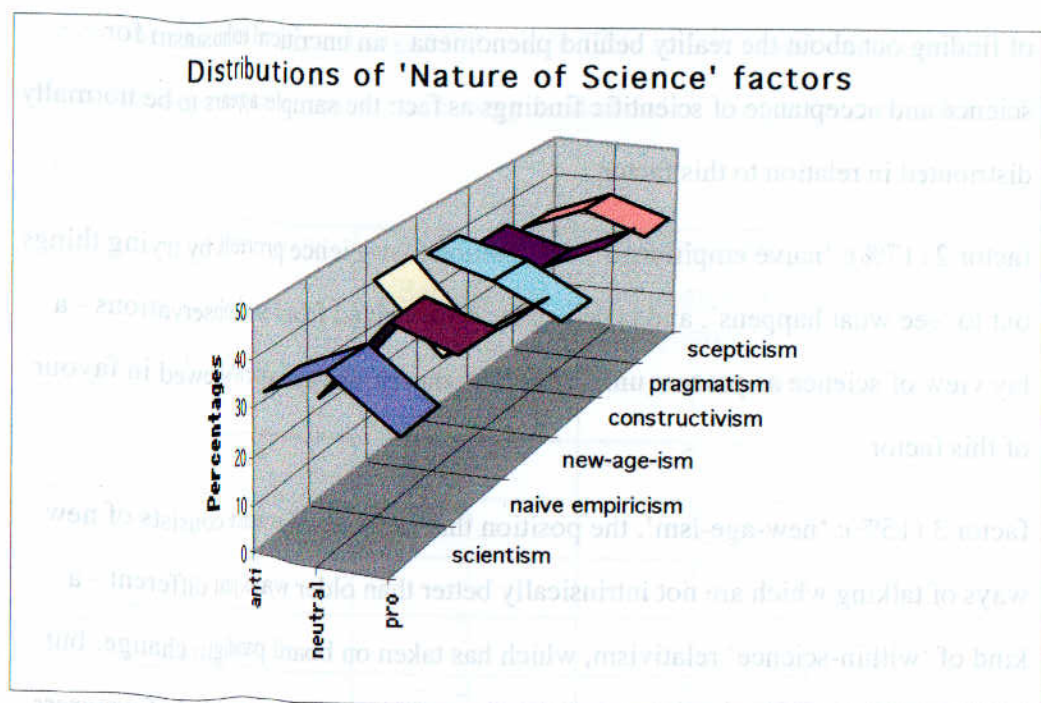
7.2.4 The nature of science

The data consist of ‘level of agreement’ responses in the range 1 (strongly disagree) through 3 (not sure) to 5 (strongly agree), to thirty-six individual statements relating to six broad areas of interest - the status and objects of scientific knowledge; its ontogeny; ‘acts of faith’ underpinning science; the role of experiment; the status and ontogeny of theory; and the nature of progress in science. Factor analysis was applied in an attempt to identify variables that might contribute usefully to explaining differences in responses at the same time as compressing the data: this identified six factors explaining over 80% of the variance, as follows (showing the percentage of the variance explained by that factor):

- factor 1 (19%): ‘scientism’, the position that scientific method will lead to the truth, that there are no mysteries that will not eventually yield, that science is the only way

of finding out about the reality behind phenomena - an uncritical enthusiasm for science and acceptance of scientific findings as fact: the sample appears to be normally distributed in relation to this factor

- factor 2 (17%): 'naive empiricism', the position that science proceeds by trying things out to 'see what happens', and is driven by data derived from such observations - a lay view of science as process uninformed by theory: the sample is skewed in favour of this factor
- factor 3 (15%): 'new-age-ism', the position that progress in science consists of new ways of talking which are not intrinsically better than older ways, just different - a kind of 'within-science' relativism, which has taken on board paradigm change, but sees it as change of linguistic or explanatory fashion rather than any kind of progress towards better explanations: this factor appears to follow a bi-modal distribution, with relatively few taking the middle ground
- factor 4 (11%): 'constructivism', the position that science is rooted in attempts to construct explanations, which originate in speculation and the human imagination, of phenomena, which form part of theory-mediated experience: the sample seems to be biased against 'constructivism', which is what might be expected given the bias in favour of 'naive empiricism'
- factor 5 (10%): 'pragmatism', the position that truth, coherence, and correspondence with reality are not worth pursuing or unattainable, and that what matters is the usefulness of science in helping us understand and influence our experience - which may have something in common with the views of technologists, see e.g. Mokyř 2000: this seems to be another bi-modal distribution, though less pronounced than 'new-age-ism'
- factor 6 (9%): 'scepticism', the position that science has no claims to specialness, and is no more likely to be true than 'common sense' - perhaps a kind of pan-epistemological relativism, or perhaps simply a naïve rejection of the non-commonsensical: this factor appears to be normally distributed.



These factors seem to cover much of the ground sketched out in the Literature Review chapter, in relation to the continuum of views of between philosophers and the public - in scientism we might find Lakatos, and proselytisers of hard-line reductionism like Richard Dawkins; naive empiricists are in the middle of the lay public end of the continuum; new-age-ists have much in common with the relativism of Collins and Latour; constructivists emphasise the sense-making intelligence behind theory and observation, echoing hypothetico-deductivism; pragmatism might be a lay rendition of Rorty; and scepticism may reflect a thorough-going relativism, or a straight rejection of science.

7.2.5 Purposes of primary science education

Developing an enquiring mind, learning to enjoy science lessons, and making connections with everyday experience, rank highest among the possible purposes of primary science teaching; learning to use correct scientific vocabulary, recording results and writing up investigations, and developing a sceptical approach to assertions and evidence, rank lowest.

Three factors seem to underlie the sample's views on the purposes of primary science, explaining some 77% of the variance, as follows (showing the percentage of the variance explained by that factor):

- factor 1 (46%): 'connect and enjoy': connecting with everyday experience and other subjects, and enjoying science and learning about the natural world: the sample is skewed in favour of this factor.
- factor 2 (20%): 'methodism': recording results, writing up, measuring, correct use of equipment, devising and conducting fair tests: distribution is approximately normal.
- factor 3 (12%): 'wondering': nurturing and developing a sense of wonder: the sample is skewed in favour of this factor.

7.2.6 The role of subject knowledge in primary science teaching

The sample was split 50:50 on the role of subject knowledge in primary science teaching: half agreed with the proposition that 'if you don't know it, you can't teach it', offering as warrants the *fear* of teaching incorrect science, and the need for subject knowledge to:

- answer children's questions
- provide scaffolding
- deliver content
- teach confidently
- plan and assess well
- position content in relation to curriculum and progression
- make content interesting.

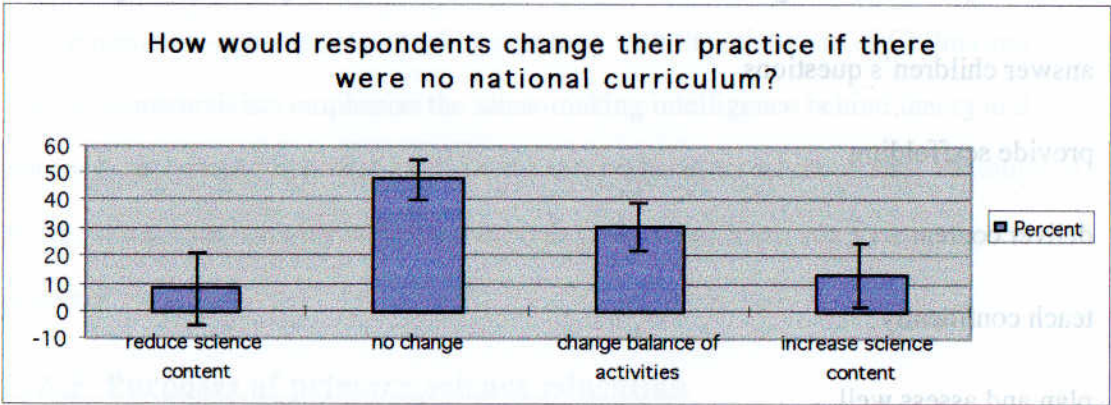
The other half disagreed with the proposition. Most offered an explanation of their position: these were unanimous in the view that teachers inevitably learn as they teach. Many argued that this actually improves their teaching, by making their relationship with the children more equal, raising the children's self-esteem, and modelling *how* to learn

(i.e. the meta-cognitive processes involved in learning) for the children. Nearly all felt that this was a positive benefit, both to the children and to themselves, by way of developing their professional practice, though some saw it as a necessary evil; others stressed the importance of collegial support.

7.2.7 Preferred directions for the development of the curriculum and practice in primary science

Respondents were asked how they would change their science teaching if there were no National Curriculum:

- 8% would *reduce* the amount of science they teach;
- 48% would make *no changes* at all;
- 31% would *change the balance of activities* while leaving the amount of time devoted to science unchanged
- 13% would *increase* the amount of science they teach.



It follows that:

- 52% would change their science teaching in some way;
- 92% would spend as much or more time on science;
- 44% would change priorities and emphases.

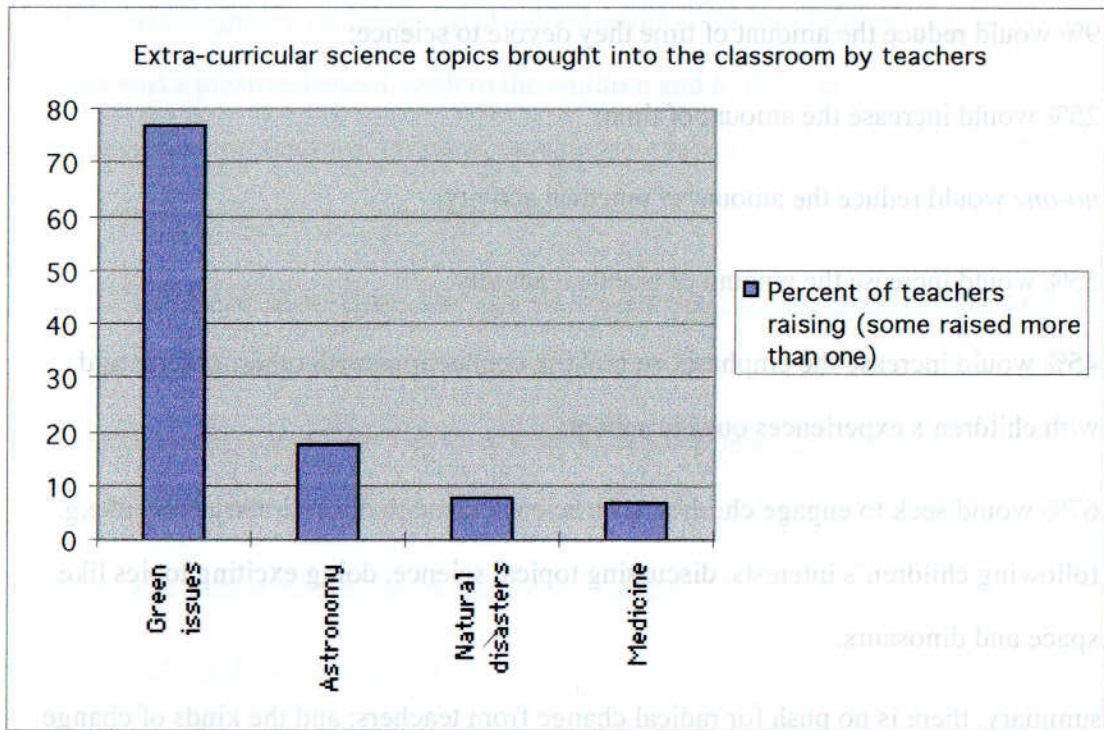
Of those who would make changes:

- 9% would reduce the amount of time they devote to science;
- 25% would increase the amount of time;
- *no-one* would reduce the amount of practical activity;
- 55% would increase the amount of practical activity;
- 45% would increase the emphasis on making connections with other subjects and with children's experiences outside school;
- 67% would seek to engage children with science through discretionary content e.g. following children's interests, discussing topical science, doing exciting topics like space and dinosaurs.

In summary, there is no push for radical change from teachers; and the kinds of change that are sought are in the directions of reducing or de-emphasising prescribed content, increasing or re-emphasising practical work, and increasing teacher autonomy, for example in flexibility to spend more time on what the children show interest in.

7.2.8 Extra-curricular science

Over 70% of the sample bring extra-curricular science into their classrooms. Those who do not, cite lack of time as the main reason. Those who do bring in extra-curricular science focus most on environmental and 'green' issues, including global warming, atmospheric pollution, the GM Foods debate, and resource depletion. Astronomy and topical issues from the media, like natural disasters, also feature quite often - astronomy may have been unusually high because of the impending 1999 total eclipse of the sun in south-western England.

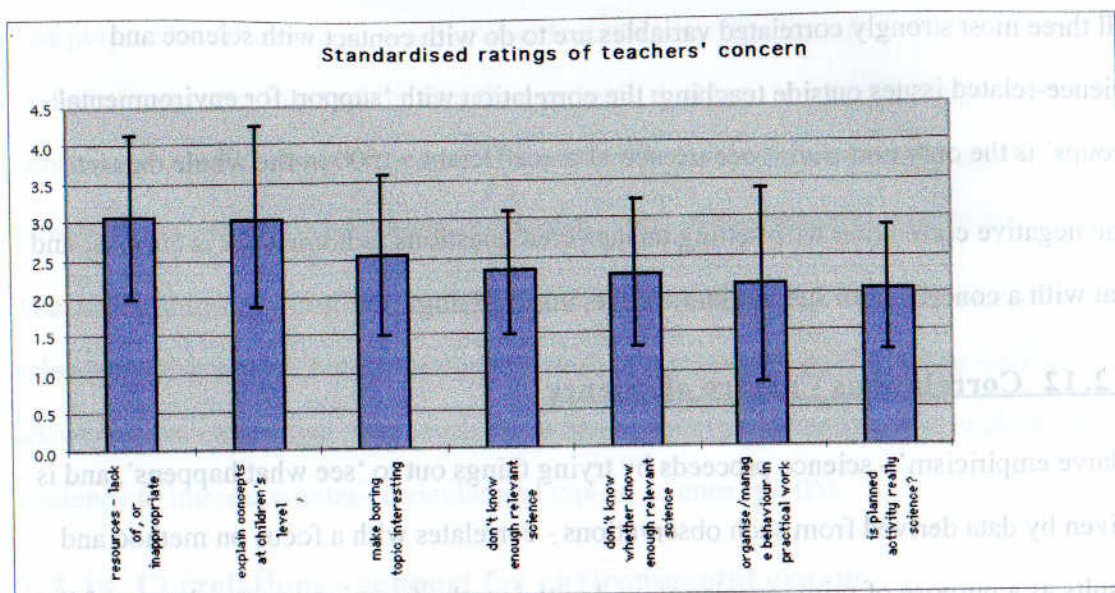


7.2.9 Professional development: how would they improve their own science teaching?

79% of the sample felt they could improve their science teaching. 65% of these want to do this by working on their 'experimental and investigative' science, primarily by improving their ability to teach content through practical work, amongst other means; and 33% would do it by improving their science content knowledge. Others mention problems with teaching science to the very young, and to lower ability children; and the scope for improvement offered by collegial sharing and mentoring.

7.2.10 Concerns in relation to science teaching

The teachers' main concerns in relation to science teaching are to do with lack of or inappropriate resources, and the problems of explaining science concepts at the children's level: these are each a 'frequent and major' concern to around 25% of the sample, and are not significantly correlated.



Three underlying factors explain 81% of the variance in teachers' concerns:

- factor 1 (46%): concern about their own subject knowledge and meta-knowledge (do they know enough relevant science; do they know whether they know enough relevant science; is what they are planning to do really science?): this factor is approximately normally distributed, with a few outliers with high levels of concern;
- factor 2 (18%): concern about communicating with and engaging children (making it interesting, explaining concepts at the child's level): this factor seems to have a bi-modal distribution;
- factor 3 (17%): concern about classroom management and organisation, especially in relation to practical work: this factor also seems to have a bi-modal distribution.

7.2.11 Correlations - level of comfort with science teaching

Level of comfort with science teaching is strongly correlated with support for environmental groups, being interested in science outside school, and following science in media (on t.v./radio) ($p < .001$ in all cases); less strongly with seeing 'making connections' as an important purpose of primary science, with doing science, especially chemistry, to GCSE, and good memories of school science ($p < .05$); and is negatively correlated with setting unanswered questions as homework, and with concern with subject knowledge ($p < .01$).

All three most strongly correlated variables are to do with contact with science and science-related issues outside teaching: the correlation with 'support for environmental groups' is the only non-trivial occurrence of a coefficient $> .500$ in the whole dataset.

The negative correlation with setting unanswered questions as homework is curious; and that with a concern with subject knowledge, unsurprising.

7.2.12 Correlations - nature of science

'Naive empiricism' - science proceeds by trying things out to 'see what happens', and is driven by data derived from such observations - correlates with a focus on method and results as a purpose of primary science, and with length of service as a teacher ($p < .01$).

'New-age-ism' - progress in science consists of new ways of talking which are not intrinsically better than older ways, just different – correlates significantly with level of comfort with music teaching ($p < .01$), and negatively with a preparedness to find out about issues raised in class, and with taking science to A level ($p < .05$).

'Pragmatism' – philosophical considerations are unimportant, what matters is the usefulness of science in helping us understand our experience – correlates significantly with seeing the development of a sense of wonder as a purpose of science teaching, and with entering teaching as a mature person ($p < .01$).

There are only weak correlations with the 'scientism', 'constructivism', and 'scepticism' factors.

7.2.13 Correlations - purposes of primary science education

The purpose tagged 'methodism', emphasising recording, measuring, fair testing, correlates significantly and perhaps surprisingly with comfort with geography teaching ($p < .001$); and with a preference for finding things out for the children when unable to answer a question in class, and a 'naive empiricist' view of the nature of science ($p < .01$). There is also an interesting correlation at $p = .013$ with a concern about subject knowledge.

The purpose of developing a sense of wonder correlates significantly with the two preferred responses to questions that the teacher is unable to answer which emphasise a constructive, in-line response to queries in which the teacher models meta-cognitive processes in discourse; and with a 'pragmatist' view of the nature of science ($p < .01$).

The 'making connections' purpose correlates unsurprisingly with being interested in science outside school, being comfortable with science teaching, discussing the kinds of answer and evidence one might look for, when unable to answer question in class, and a tendency to introduce extra-curricular and topical science ($p < .05$).

7.2.14 Correlations - support for environmental groups

The question about environmental groups was included after reflecting on references by several pilot study interviewees to 'green' issues. Support for such groups correlates significantly with comfort in science teaching and with a response to difficult questions (discussing the kinds of answer and evidence one might look for) that models meta-cognitive processes ($p < .001$); and with following science in the broadcast media ($p < .01$). There are suggestive weaker negative correlations with levels of comfort with P.E. and music teaching ($p < .05$).

7.2.15 Correlations - dealing with questions you cannot answer immediately

Two of the possible responses imply that the teacher will model the meta-cognitive processes involved in thinking about, and lead collaborative discussions on:

[i] the kinds of answer that might be acceptable, and the kinds of evidence one might seek for it, and

[ii] how to find out from other reference sources.

These imply a joint teacher-pupil project to solve the problem, and are significantly correlated with each other, with an interest in science outside school, and with the purpose of developing a sense of wonder. The former is also significantly correlated

with being comfortable with D&T teaching and with support for environmental groups, and negatively correlated with being comfortable with P.E. teaching.

[i] Discuss kinds of answer and evidence:

	Pearson correlation coefficient	p
level of comfort with D&T teaching	.433	.000
support for environmental groups	.399	.001
purpose - wonder	.390	.002
interested in science outside school	.383	.002
unable to answer question – discuss reference sources	.358	.005
following science in media – t.v./radio	.300	.019
purpose – ‘making connections’	.297	.020
age group	.260	.043
mature entrant to teaching	.260	.043
level of comfort with Art teaching	.257	.045
level of comfort with P.E. teaching	-.353	.005

[ii] Discuss reference sources:

	Pearson correlation coefficient	p
interested in science outside school	.362	.004
purpose - wonder	.361	.004
unable to answer question – discuss kinds of answer and evidence	.358	.005
nature of science – ‘pragmatism’	.283	.027
support for environmental groups	.263	.041
following science in media – newspapers	.254	.049

Responses such as [iii] ‘Find out for homework’ and [iv] ‘I’ll find out for you’ represent opposite ends of the continuum at the middle of which a joint teacher-pupil project to answer the question sits.

The former is significantly negatively correlated with level of comfort with science teaching; the latter is positively correlated with the purpose tagged ‘methodism’, and negatively with comfort in D&T teaching, and with following science in the newspapers.

[iii] ‘Find out for homework’

	Pearson correlation coefficient	p
concern – subject knowledge	.305	.017
level of comfort with P.E. teaching	.257	.046
following science in media – t.v./radio	-.269	.036
level of comfort with science teaching	-.378	.003

[iv] ‘I’ll find out for you’

	Pearson correlation coefficient	p
purpose – ‘methodism’	.391	.002
GCSE in physics	-.253	.049
nature of science – ‘new-age-ism’	-.253	.049
number of science GCSEs	-.286	.025
level of comfort with D&T teaching	-.360	.004
following science in media – newspapers	-.380	.002

7.3 Summary

The most interesting points to come out of this survey are:

1. Science remains amongst the three or four subjects that primary teachers feel most comfortable in teaching.

2. Six factors seem to underlie teachers' views of the nature of science (or, to put it another way, any one teacher's view of the nature of science can be fairly accurately characterised by where they stand on each of these six issues):
 - 'scientism' - an uncritical and optimistic enthusiasm for science
 - 'naive empiricism' - equating science with trying things out to 'see what happens'
 - 'new-age-ism' - science is just another way of talking
 - 'constructivism' - science constructs explanations which originate in speculation and imagination
 - 'pragmatism' - what matters is the usefulness of science in helping us understand our experience
 - 'scepticism' - science has no claims to specialness, is no more likely to be true than 'common sense'.
3. Teachers split 50:50 on the role of subject knowledge in primary science teaching: half agree that 'if you don't know it, you can't teach it', and half argue that 'learning as you teach' is inevitable, and beneficial to teacher and pupils.
3. Teachers' main concerns are resources, and being able to explain concepts at the children's level. A small minority are very concerned about their subject knowledge.
4. 80% of teachers believe they could improve their science teaching. Most of these would focus on their teaching of 'scientific enquiry', especially on how to teach content through practical work.
5. Over 70% of teachers bring discretionary science content into their classrooms, most of which has an environmental or 'green' focus.
6. In terms of improving the curriculum and practice in primary science, there was no overwhelming push for radical change from teachers - half would like to see no change at all. Where changes were sought, they were in the directions of reducing

or de-emphasising prescribed content, increasing or re-emphasising practical work, and increasing teacher autonomy, for example by way of increasing discretionary content.

It is interesting to note that the revised National Curriculum, published in September 1999, after the survey was conducted, is broadly consistent with at least some these aims: it generally adopts a more active voice, re-emphasising the need to teach content through practical work; it makes minor reductions in the prescribed content; and it requires teaching of content through 'a range of domestic and environmental contexts that are familiar and of interest' to children.

7. There is a strong correlation between level of comfort in teaching science, and level of support for environmental groups like Greenpeace and Friends of the Earth.

Those who are most comfortable with science teaching are:

- most likely to be sympathetic towards or members of environmental groups
- most likely to follow science outside school, especially on t.v. and radio
- likely to see making connections (between science and other subjects, and between science and children's lives) as the main purpose of primary science teaching
- likely to have done at least one science to GCSE, and have generally positive memories of school science
- unlikely to respond to questions they cannot answer by asking children to find out for homework.

Supporters of environmental groups are also very likely to favour responding to questions they cannot answer by discussing the kinds of answer that might be expected, and the kinds of evidence that might be used to decide; and are unlikely to be comfortable with P.E or music teaching.

Other interesting correlations include:

- those who are most comfortable with geography teaching are likely to focus on 'method' (recording results, measuring, etc.) as the main purpose of primary science; to prefer dealing with questions they cannot answer by finding out for the children; to favour a 'naive empiricist' view of the nature of science; and to be concerned about their own science knowledge
- those who see 'developing a sense of wonder' as the main purpose of primary science are likely to prefer responding to questions they cannot answer by discussing what kinds of answer and evidence might be sought, and how they might be obtained - constructive, in-line, collaborative responses; and to favour a pragmatist view of the nature of science.

8. Reliability and Validity

It is difficult for me to separate the case studies I have written from the people I have come to know and call friends; and to evaluate the case studies in terms of whether they convey an authentic and coherent picture of each person - of course to me they do, that's why I wrote them as I did - but do they to other people? Two people have read all of them, and several have read some of them. They have agreed that the case studies give a convincing picture of the 'personhood' of each participant, by means of some 'human faculty' of the readers, of apprehending the wholeness and authenticity of a person.

This might be termed a 'holistic' test of the validity and reliability of the case studies: other more specific tests have looked at the following:

- Consistency between data gathered by different techniques within each case study - protocol analyses, lesson observations, semi-structured and biographical interviews, and reflective comment - provides strong evidence for the internal validity and reliability of the case studies.
- Triangulation between case studies and survey data helps in interpreting survey respondents' answers, and provides warrants for the reliability of the survey instrument, and the external validity of the case studies.
- Typicality of case study participants was assessed by placing case study participants in frequency distributions generated from survey data.
- A more abstract and speculative form of triangulation between three quite different derived indicators - one abstracted from each case study as a whole; one drawn from comparison between each participant's theories of learning and their classroom practice; and one drawn from comparison between their survey answers and their answers to specific questions in interview - provides additional confirmation of the internal validity and reliability of the case studies.

8.1 Internal consistency within case studies

The views given in interview, the self-reported thinking during planning, the actions in teaching, and the reflective comment of each participant, exhibited high degrees of internal consistency. This consistency within an individual's account, and the contrast between one individual and another, is illustrated below by summarising and comparing selected aspects of the data on the two very experienced male teachers who participated, Andrew and Howard.

8.1.1 Point-by-point comparison of two cases

8.1.1.1 School memories: life history interview

Andrew recalls vividly one particular teacher from his primary school in what is now Zimbabwe, who taught the class how to see nature, and who was always ready to pursue children's interests: for example "if a child brought in a snake, or .. I remember one child brought in a leopard cub, that had been abandoned .. and snakes and birds eggs and all sorts of things, and .. the lesson would be around that, which was great."

At secondary school too his memories are of interesting and enjoyable episodes with specific teachers, such as the physics teacher who rooted everything in everyday life and technology, and led into the science from there. He took one GCE O level in science (General Science).

Howard found it very hard to remember anything about his experiences at a primary school on the outskirts of Manchester except that it was a good, formal school, until something suddenly came back to him: "Oh! I used to help a teacher. . I used to help clean the cupboard.. I'd take everything out and then put it all back and take it all out again so by the time he arrived it had never been finished.. I used to actually get away with some lessons doing that! .. It was a stock cupboard, so it was all books and papers and everything."

His secondary school too was very formal, with “good solid teachers”. He did a lot of “copying off the board” and watching teacher demonstrations. He took one GCE O level in science (Biology) and two A levels (Botany and Zoology).

8.1.1.2 Approaches to science teaching: planning, lesson observations, interviews 1 to 5

Andrew believes that children’s responses to being trusted and given autonomy include enhanced self-esteem, interest and engagement, and that these lead to better learning.

Learning consists of connecting the new into, and/or adjusting connections or evaluations in, inter-related networks of concepts, relationships, beliefs, values and meanings, which include cognitive, affective and reflexive elements, through action, observation and engagement in discourse. He therefore provides the minimum amount of scaffolding to enable each child to get results they can be proud of, and sets up the bulk of his science teaching so that children can choose who they want to work with, if anyone; pursue their own lines of enquiry; take as much time as they need having concrete experience; devise their own tests; and reach their own conclusions. He thinks that there are so many areas in the existing curriculum that interest children that there is “no excuse for them to be bored and turned off”.

Howard’s foci in primary science are vocabulary; providing the “building blocks” for later understanding; and “straightening out” misconceptions. He sees the National Curriculum as providing “meaningful contexts” for science content, and the chief organising metaphor in his interaction with it is that of “clearing up” bullet points. Though investigations are important, time pressures and the dearth of topics that “lend themselves” to practical work mean that most of the science is teacher demonstration or ‘chalk and talk’.

8.1.1.3 Worksheets: planning, lesson observations

Andrew’s ‘Design a space suit’ worksheet for a ‘properties of materials’ project in Y5 sets up a context which engages the children while leaving them considerable independence and autonomy. The worksheet supported five or six one-hour lessons

devoted to practical work, plus briefing and writing-up time, and was designed to satisfy learning objectives related to content knowledge, scientific enquiry and process skills, from the science curriculum, with a nod in the direction of problem-solving and design for D&T.

Design a space suit

You and your team have been given the task of designing a space suit for a voyage to a new planet. You need the suit to cover the body and head.

You do not know much about the planet except for the following things:

- * During the day the planet gets very hot. You will need a material that will let you sweat, one which will let water through.
- * Small fiery meteorites sometimes fall onto the planet. The traveller's suit should not burn too easily.
- * The space traveller will need to climb over rocky terrain to collect rock samples. The suit needs to be tough, so not tear or wear out too easily.
- * Electrical storms are quite common. The suit should protect the wearer, so not conduct electricity.

Test the materials fairly to see which one is best over all. Record your results for each test. You may decide to make the suit from one material or make different parts from different materials. Present your design clearly, ready for the voyage.

Howard's worksheet for a materials lesson in Y3 is designed to recap and reinforce the science curriculum 'bullet points' that the series of lessons has 'cleared up'. The example below also shows the answers written in by one pair of pupils, having been talked through them several times, after the manner of a catechism. The completed worksheet will be stuck in the children's science books, to act as a revision aid for Y4 'mini-SATs',

and as evidence (for example for OFSTED inspectors) that the children’s curricular entitlement has been fulfilled.

Worksheet 1

Rocks + Soil

The world is made of rock. It is the material which the planet is made from. When rock is broken into little pieces and mixed with rotting dead things it is soil. Plants live in soil.

Mr Hughes filled a bowl with water and put a pot of soil in. We saw lots of bubbles as the water pushed the air out.

We wondered if there was air in rock. We put a piece of rock in 600ml of water and left it for a week.

1.

What is the world made from?
rock

2.

What is soil?
rotting bodies, dead leaves, broken bits of rock, sand

3.

Why did bubbles come out of the soil?
because soil has holes in it and water went into the holes and pushed the air out

4.

What do plants live in?
Plants live in soil that makes them grow

5.

Did the rock have air in it?
the rock had air holes in it

6.

How long did we leave the rock in water?
one week

7.

We started with 600ml of water. What was the amount after a week?
Slate 25ml sandstone 50ml absorbed

8.

Does rock absorb water?
it does absorbed

9.

Is all rock the same?
no it isn't

10.

What science have we done on rocks and soil?
*looking at properties of material,
setting up an experiment to answer a question, is rock porous?*

8.1.1.4 Subject knowledge and professional development: interview 4 and throughout

Andrew believes that subject knowledge to the level of GCSE/O level provides an adequate platform for starting to teach a subject at KS2, from which an interested and motivated teacher will be able to develop. He sees himself as still learning and his own practice as still developing: he is becoming less confident that there are any right answers in teaching, and goes to greater lengths to accommodate differences between children. He has no serious concerns when approaching a new topic, having a repertoire of tried and tested approaches to draw on.

Howard maintains that good subject knowledge is essential, but that “you don’t have to be a scientist to teach science”. He has lost interest in his own professional development, finding even reacting to externally initiated change increasingly difficult. His concerns when approaching a new topic include getting the science concepts and vocabulary right; communicating them to the children; and devising entertaining demonstrations.

8.1.1.5 Nature of science: interview 3 and throughout

Andrew is wary in discussing his views of the nature of science, recognising it as a complex raft of issues which can be approached from many perspectives. He retains a wide-ranging scepticism; rejects phenomenalism; and sees science as a human enterprise, an elaborated form of something that groups of children often do spontaneously, wherein process establishes validity. Science is the main engine of change in our world-view and hence is inextricably bound up with changes in our moral framework. Scientific literacy resides as much in meta-knowledge as in knowledge - in being aware of the strengths and limitations of personal knowledge, and of scientific knowledge in general: in relation to a real-world issue he admits ignorance, suggests that the research has not been done, and remarks that: “we often act on evidence which really doesn’t have much basis in reality”.

The views of science implicit in his planning and teaching are consonant with the above and with each other, re-iterating the importance of a cycle of thinking (about evidence and possible explanations) and investigation (to get more evidence), and stressing that, though precise and accurate measurement is to be preferred, any evidence is better than none, and with enough imagination, it is usually possible to devise some method of obtaining it.

Howard sees scientific knowledge as a tentative but objective personal construction based on theory, hypothesis, experiment, and precise, replicable results, requiring trust in the methods and integrity of scientists. It is one of many ways of knowing about the world, of equal validity; but is unusual in its suspension of morality - it is an area where ends justify means that in other contexts would be morally unacceptable. He argues that

scientific literacy makes no difference to people's lives, except in so far as lack of it impoverishes them: in relation to a real-world issue he holds contradictory views, accepting one on the basis of trust in authority, and the other on the basis of personal experience.

The views of science implicit in his planning and teaching are in places in tension with each other and the above. A politically correct relativism is mandated to avoid offending those with strong religious beliefs that are seen as incompatible with science, which Howard seems to be ambivalent about, but at least in part to welcome. There are tendencies to value the surface form of scientific symbolism and vocabulary above its meaning; to value correctness of vocabulary above quality of thought; to value the form and expectedness of results over their validity, reliability and intelligibility; and to adopt a pessimistic approach to the practicability of investigating a wide range of phenomena in the classroom.

8.1.1.6 Relationships with children: lesson observations and throughout

Andrew is very sensitive to the differences between children, being aware of their preferences for working in same-sex or mixed groups, or alone; the need of some for the intellectual stimulation of exploring beyond their brief, while others need simply to gain concrete experience; the variety in home lives and backgrounds, maturity, interests, and awareness of topical issues. He treats them with respect, trust, patience, fairness, kindness and tolerance; encourages them to act autonomously, and helps them take on roles which facilitate this; and is both discriminating and generous in giving positive feedback.

Howard is interested in children's cognitive processes and conceptualisations: their thinking is not logical, and their everyday understanding includes some "really interesting mistakes". He is aware of a number of problem areas in terms of specific content (e.g. Y3 children find understanding 'the seasons' impossible) and in general (e.g. they find it hard to understand causal explanations). His dialogues with children are usually directed to eliciting specific items of vocabulary, and the children's normal roles

are to listen, guess, and assist in demonstrations. He takes pride in knowing each individual in his class, and is generous with feedback, treating boys and girls slightly differently in this regard.

8.1.1.7 Internal corroboration within Andrew's and within Howard's account

Looking only at the paragraphs about Andrew above, one may get the sense of a coherent personhood, the unifying thread from which their consistency flows: the same might be said of the paragraphs about Howard. This is, though, reinforced by the juxtaposition of paragraphs about each, where we see the *difference between* two people running through each aspect from which we look at them - vivid memories of a leopard cub beside dredged-up memories of tidying a stock cupboard; predominantly hands-on science beside teacher demonstration; a worksheet that creates an engaging context beside one which 'clears up' curriculum bullet points; and so on. It is perhaps the consistency of the difference between the individuals that most tellingly points up the internal consistency of their accounts.

8.1.1.8 Independent observers' corroboration of internal consistency

The above sections demonstrate the internal consistency within two of the five case studies. In an attempt to verify this with independent assessors, extracts from the case studies were presented to a group of four social science research students. For each teacher, the extracts related to: an example of their memories of primary school; an example of their views on primary science teaching; and an example of a worksheet used in an observed lesson. The group was then presented with five quotes about memories of science learning in secondary school - two from case study participants, and three from other teachers who had taken part in the pilot, but not the main study. The group were readily able to reach consensus on the identity of the originators of the two quotes from case study participants; and were fairly sure that none of the other quotes were likely to have come from them.

8.1.2 Summary of differences and similarities across five cases

Irene and Keith, teaching the same age group, in the same school, influenced by very similar tensions and constraints, and both with less than five years' teaching experience, nevertheless have very different values and professional identities, and rarely respond similarly in either survey or case study data. Howard and Andrew, both males, both the children of teachers, both in their late forties at the start of the project, might be expected to hold similar views: but as discussed above, the case study data show them to be radically different, and this is reinforced by their responses to the survey. Andrew and Linda, on the other hand, have little in common by way of background, but interesting similarities emerge in both the survey and case study data, for example in relation to:

- their feelings about science in their own schooling
- their contacts with science in the media, and feelings about environmental groups
- their views on the role of subject knowledge in primary science teaching
- rankings of their levels of comfort with different subjects: both put Art, D&T, Science and English in their top four (as does Irene)
- their views on how to improve the curriculum and practice
- their approaches to topical/extra-curricular science
- their views on how best they could develop their own science teaching - by learning and bringing in to the classroom more up-to-date research
- their views of the purposes of primary science teaching
- their theories of learning: both the substance of the theories, and their degrees of interconnectedness
- the degree of autonomy manifest in their claiming control of their professional development and destiny
- the amount of time devoted to autonomous, hands-on practical work in their lessons

- their sensitivity to the differences between and different needs of individual children
- their readiness to bring family members, scientists, interesting people into their classes
- their interest in and professional involvement with colleagues
- their respectful and trusting relationship with children.

There are differences, though, most notably in relation to their views of the nature of science, where Andrew tends to be rather cautious and diffident, whereas Linda seems to be interested in and enthusiastic about a variety of ideas, some with a rather 'post-modern' slant. Thus though their views on and knowledge of science differ, their theories of learning, their views of teaching in general and of science teaching in particular, their planning, and their actual teaching, are similar in many ways.

8.1.3 Exceptions to internal corroboration - theories of learning and classroom practice

Exceptions to internal corroboration were anticipated, and found, in the gap between intentions and personal theories enunciated in discussion and during planning, and actions in teaching. There was considerable variation in the richness and interconnectedness of participants' theories of learning, hence it is not possible to derive useful direct comparisons of practitioners' theory and practice - it could be trivial to implement a very simple 'theory' in toto, but more challenging to implement more than a fraction of a very rich and diverse theory. Thus participants are compared on the basis of a limited number of specific aspects of their theories of learning, in terms of what their theory was in each area, and how they were observed to implement it in class. Possible explanations for any discrepancies are then discussed. Three such aspects are considered:

- the importance of direct, hands-on investigation by pupils
- the importance of making connections with pupils' prior knowledge and experience
- the importance of pupils' self-esteem and personal development.

Time spent in each participant's observed lessons on hands-on investigation is as follows:

	Andrew	Howard	Irene	Keith	Linda
hands-on investigation (mins)	115	26	15	2	95
total duration of observed lessons (mins)	135	220	115	110	165
percentage hands-on	85%	12%	13%	2%	58%

All thought hands-on practical work important in theory, but only Andrew and Linda seemed to accord it importance in practice. The others were aware of the mismatch: Irene and Keith explained that they were constrained by teaching Y6, had to 'cram' a year's curriculum into less than two terms, to allow time for revision, and hence could not spare the time for much practical work - though the small amount of time Keith devoted to it was taken up with very memorable activity. Howard complained that the amount of content he had to get through precluded extended practical work - during the project he taught Y3 then Y5. Linda, teaching Y3 in a different authority, and Andrew, teaching Y5 in the same LEA as Howard, and using the same LEA scheme of work, both found time - indeed in the observed lessons, both devoted more than half the available time to hands-on work. The only practical activity in Howard's observed lessons closely followed a suggestion from the LEA scheme of work, but problems arose coping with any departure from the script, suggesting he may have been 'teaching by rote' in this instance.

Connecting with children's prior experience and learning was an outstanding feature of Irene's teaching, and ubiquitous in Andrew and Linda's classes. Connections were also made in Howard's classes, but originated exclusively from the teacher: Keith was similar but less extreme in this regard.

Only Howard did not mention building children's self-esteem as an important part of learning: the others seem to regard it as fairly central to what they do, and to put that belief into action. Howard rewards compliance with verbal praise, and is otherwise

rather indiscriminating, which may devalue it for the children, whose predominant roles are audience for and assistant in ‘magic tricks’.

The following table was derived from the above. In seeking to derive a simple index from something as complex as the relationship between a professional practitioner’s theorisation of their role, and their actions in putting it into practice, it is inherently speculative and abstract: its value lies in this abstraction, in that if valid it reduces an enormous amount of data to a single number, for each participant. In the table below, the level of agreement between the three aspects of each participant’s theories and practice is rated on a scale from 1 to 5, where 1 = complete agreement, and 5 = complete contradiction between theory and practice.

	Andrew	Howard	Irene	Keith	Linda
hands-on investigation	1	4	3	4	1
making connections	1	4	1	3	1
pupils’ self-esteem	1	3	1	1	1
<i>aggregate</i>	<i>3</i>	<i>11</i>	<i>5</i>	<i>8</i>	<i>3</i>

This table represents the author’s codings: an independent coder, who had read all the case studies, and had access to the transcripts and observed lesson descriptions underlying the case studies, came up with very similar results, and with *identical aggregate rankings*.

It will be noted that Andrew and Linda most closely match theory and practice, evidence of well-developed and thorough-going professional identities. Irene comes next, perhaps because she is slightly less experienced and still developing her professional identity: perhaps because she is operating under more severe constraints in Y6. Keith is under the same constraints, and even less experienced - so perhaps both factors have an influence. Finally, Howard, though the most experienced of the group, seems less able to match his personal theory with his practice, at least in the observed lessons, and indeed seems positively defeatist about the possibilities of doing so, perhaps suggesting something dysfunctional in his professional practice.

8.2 Triangulation between survey and case studies

Triangulation between survey data and case studies served three related purposes: firstly, to help interpret survey respondents' answers; secondly, to show the degree of reliability of the survey data; and thirdly, to show that the case study participants were not unusual or atypical people. The first two purposes were served by having the teachers who participated in the main study also complete the survey questionnaire, and comparing their answers to the survey questions with what they said and did in the case study interviews and observations. The third was served by locating the participants in the frequency distributions of the survey respondents.

8.2.1 Interpreting survey respondents' answers

It is in the nature of a survey that it will probe in a few questions, an area that in face to face semi-structured or unstructured interviews one might talk about at length and from various perspectives. For example, survey respondents' thinking about the nature and ontogeny of scientific theory is probed by asking for level of agreement with six simple statements; views of how the science curriculum could be developed are probed by two questions. The case study participants' answers to such questions in the survey can be compared with their extensive discussion of these issues in the interviews, and by what they try to do in their planning and teaching, to explore the uncertainties, ambiguities, intentions and meanings that lie behind the bald answers given in the survey, helping in and giving depth to the interpretation of the survey responses.

8.2.2 Reliability of the survey data

The survey data consist of: responses to twenty factual questions; responses to ninety-eight non-factual questions; and fourteen factors generated from answers to four groups of non-factual questions, such as those relating to the nature of science. For each of these, the case study participants' survey responses were compared to their statements and actions as reported in the Case Studies chapter.

There are four possible outcomes of such a comparison: the answers are completely congruent; the answers are congruent, but either or both sources provide compatible expansions or extensions to positions in the other; the answers are ambivalent, partly congruent, partly contradictory; the answers are completely contradictory. More varied responses can be expected in interview: for example one question asking for a straight ‘Yes’ or ‘No’ answer in the survey, elicited an ambivalent response of ‘Well, yes and no..’ in interview in three out of five cases, and was followed by discussion of the countervailing positions.

The following table shows survey answers, in plain text, and views from the case studies (*in italics and brackets*), for those instances where there is significant ambivalence or contradiction between a participant’s case study and survey answers.

name	Andrew	Howard	Irene	Keith	Linda
Follow science in the media - TV/radio		No (<i>yes in interview, but only by accident</i>)			
Follow science in the media - books/magazines	No (<i>yes in interview, to magazines like New Scientist and National Geographic</i>)	No (<i>yes in interview - two Richard Dawkins books</i>)	No (<i>yes in interview</i>)		
Subject knowledge: if you don't know it, you can't teach it		Yes (<i>'yes and no' in interview</i>)	Yes (<i>'yes and no' in interview</i>)		Yes (<i>'yes and no' in interview</i>)
subject knowledge comment		(<i>seems very ambivalent in interview: if you don't know it, "you've got</i>	(<i>background knowledge helps make it interesting, but you can't</i>		(<i>lack of knowledge can be turned to pedagogic advantage, and help</i>

		<i>to get some INSET”: but the INSET he had gave him far too much, and “you don't need to be a scientist to teach science!”)</i>	<i>be a specialist in everything)</i>		<i>build children's self-esteem)</i>
Development of primary science teaching - given a free hand, no NC, what would you do?	<i>no change (no change to curriculum, which is now much more flexible: but change to school's scheme of work)</i>	<i>reduce science content ('no change to curriculum' in interview: “Leave it alone. Leave it absolutely the same. Leave it as it is. It's good.”)</i>	<i>no change ('change balance' in interview)</i>		<i>no change (several detail changes in interview)</i>
explanation of change envisaged	<i>(more flexibility; better management of resources; and reverse trend to subject specialists)</i>	<i>more biology, less physical science, more time for Sc1 activities (more resources)</i>	<i>(social dimension, values discussion, green focus; more flexibility; more time for practical work)</i>		<i>(less content, more concrete experience in KS1; more on what children want to know about, e.g. the solar system, and connecting science with</i>

					<i>everyday life)</i>
Could you improve your science teaching?		Yes (<i>'no' in interview: "over the hill", too late to change</i>)			
how to improve?		Forces and energy. (<i>an intensive INSET course in physical science had given him far more subject knowledge in this area than he would ever need</i>)			
'Concerns'		(<i>also concerned with teaching the right science</i>)		(<i>no concerns expressed in interview</i>)	
Views of the nature of science					
New-age-ism	anti (<i>theoretical advance often requires new ways of looking at previous findings and</i>		very pro (<i>science is not arbitrary but always offers the possibility of substantive</i>		

	<i>theories)</i>		<i>explanation)</i>		
Scepticism		anti (<i>"children need to know it isn't fixed, there are no Truths"</i>)			pro (<i>progress in science is real and cumulative</i>)

Survey and interview responses were clearly more compatible in relation to some questions than others. Generally, where there is a difference, the case study data are likely to be more reliable and valid, for reasons discussed in the Methodology chapter: in one case the reverse seems more likely, as noted below. Survey and case study data are entirely congruent in relation to:

- background factual information
- feelings about science at school
- feelings about environmental groups
- levels of comfort in teaching various subjects (detailed rankings were not elicited in interview, but the many comments made reinforced the rankings in the survey, and none contradicted them)
- bringing topical and extra-curricular science into the classroom
- the purposes of primary science teaching.

They are fairly congruent in relation to:

- participants' contacts with science in the media
- participants' views on how they could improve their science teaching: in the survey, Howard gave the kind of positive response one might expect when something is put in writing, whereas in interview he was more resigned and cynical; Irene clarified her bald survey response that there were no aspects of her science teaching that she would

like to improve, by saying she did not want any INSET, but is aware of her practice improving through experience, and is happy with that

- participants' concerns: Howard mentioned an additional concern, and Keith expressed a positive lack of concerns, in interview, but indicated some in the survey (the latter is the instance where the survey may be more to be trusted than the interview: when asked whether he had any particular concerns about science teaching in interview, he could have said 'no' because he could not at that moment think of any, or he was not quite sure what I was getting at; when given a list of possible concerns in the survey, he ticked some, perhaps because the list acted as a reminder, or gave him a better idea of what I meant)
- participants' views of the nature of science: the degree of corroboration between survey 'factors' and positions expressed in case studies is surprisingly high, and good evidence for the 'reality' of the factors, given the challenging nature of the questions and discussions in this area, and the apparent volatility of participants' positions which, in interview, were observed to evolve over a few sentences, as in Andrew's discussion of shamanistic medicine, and Linda on the reality of electrons.

Survey responses and case studies are least congruent in relation to two issues that go right to the heart of the teachers' professional identities, where the kind of single, simple answer asked for by the survey is least likely to be satisfactory - the role of subject knowledge in teaching, and how they would change the curriculum and their practice if they had a free hand.

- Subject knowledge: 'if you don't know it, you can't teach it': Howard, Irene and Linda all assent to this proposition in the survey, but are prepared to argue both sides in interview. Keith dissents, but comments that "it's not black and white", and Andrew assents, arguing for knowledge to GCSE level as a minimum starting point for further development, in any subject you want to teach in KS2. Both Keith and Andrew amplify but do not change or qualify the substance of their views in the case study data.

- Changing the curriculum: Andrew, Irene and Linda tick the ‘no change’ box in the survey, but argue for a range of subtle changes to its content or implementation in interview. Howard, in contrast, asks for a reduction in content, and a more biological focus, in the survey, but makes an emphatic plea for no change whatsoever, in interview. The views expressed in interview seem consistent with the professional identities and positions implied by the study as a whole.

Even here, it will be noted that there are very few direct contradictions between survey response and comments in interview. Where answers differ from survey to interview, it is mostly because interviews are more discursive, and give more opportunities to explore areas of doubt or uncertainty, thus it is difficult to find real contradictions of substance in the above, as opposed to qualifications and expression of ambivalence between multiple tenable countervailing positions: most differences merely reflect the different circumstances in which the questions were asked. Only Howard gives answers that really are completely incongruent: the hypothesis is that he is answering from two different positions, or inhabiting two different identities or two different ‘poles’ of an identity, in the different situations of survey and interview.

8.2.3 Reliability indices

Simple numerical indices, to express the degree of reliability exhibited by the survey responses of case study participants, were calculated on the basis of the proportion of survey questions whose answers were compatible with each participant’s statements in interview. Issues on which any degree of contradiction or ambivalence were expressed were not included in the count of compatible answers, so many of those counted as incompatible were only trivially so. Indices were calculated for factual questions, non-factual questions, and synthesised factors, as follows:

Number of survey answers contradicted in whole or in part by case study data:

Type of question	Number of questions in survey	Andrew	Howard	Irene	Keith	Linda	Overall
Factual	20	0	0	0	0	0	0
Non-factual	98	2	6	3	1	2	14
Factors	14	1	1	1	0	1	4
Overall	132	3	7	4	1	3	18

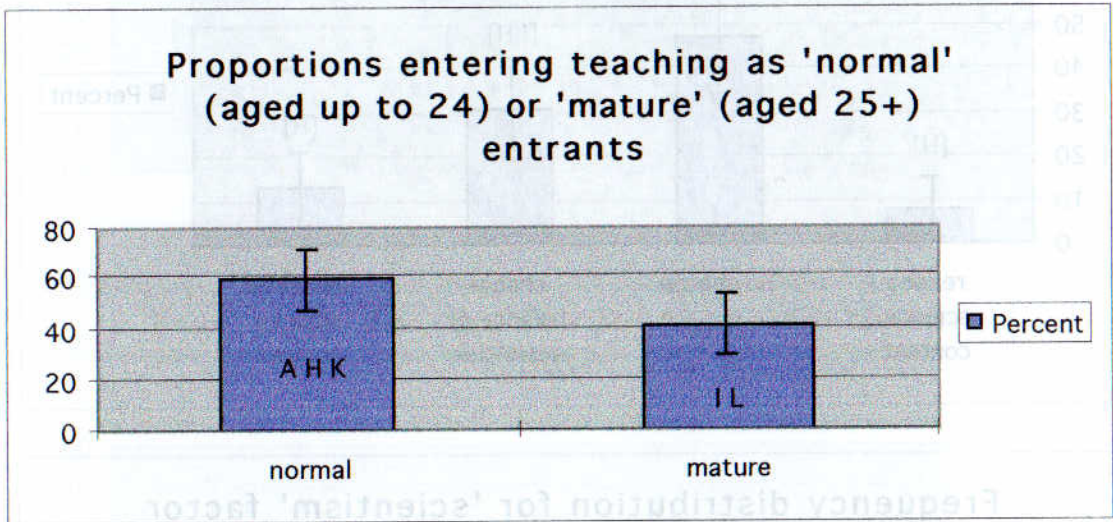
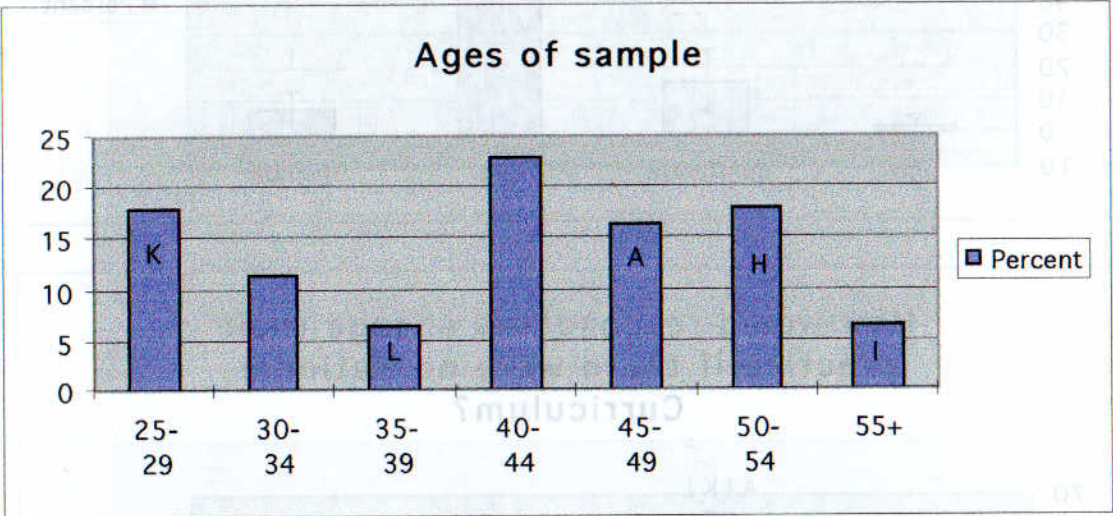
Reliability indices: number of answers that are neither contradictory nor ambivalent, as a percentage of total number of answers:

Type of question	Number of questions in survey	Andrew	Howard	Irene	Keith	Linda	Overall
Factual	20	100%	100%	100%	100%	100%	100%
Non-factual	98	98.0%	93.8%	96.9%	99.0%	98.0%	97.1%
Factors	14	92.9%	92.9%	92.9%	100%	92.9%	94.3%

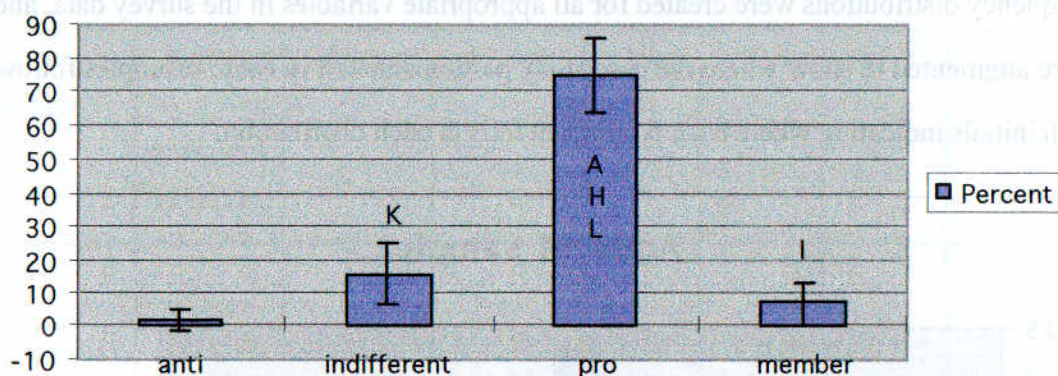
It will be noted that Keith’s reliability index is almost 100%; Andrew, Irene and Linda’s are all around 97% - mostly arising from ambivalence or qualification rather than contradictory views, i.e. the differences are largely manufactured by the different methods; and Howard’s is 94%, mostly arising from direct contradictions between survey and case study data. The overall index value is 97%, for all questions and all case study participants.

8.3 Typicality of case study participants

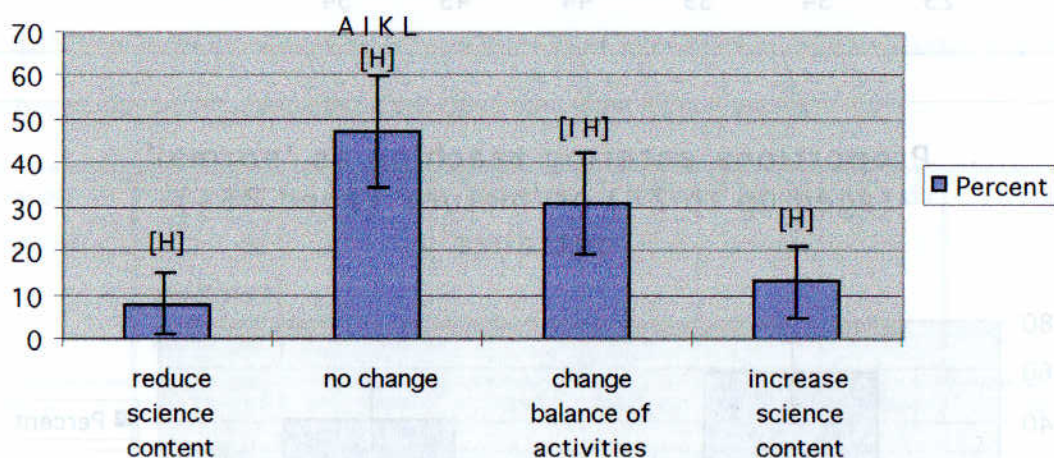
Frequency distributions were created for all appropriate variables in the survey data, and were augmented to show where the case study participants fell in each: examples follow, with initials indicating where each participant falls in each distribution.



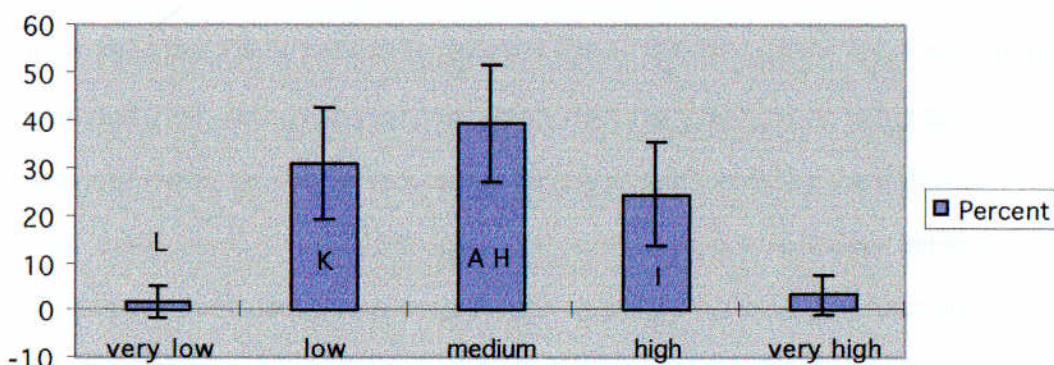
Feelings about environmental groups



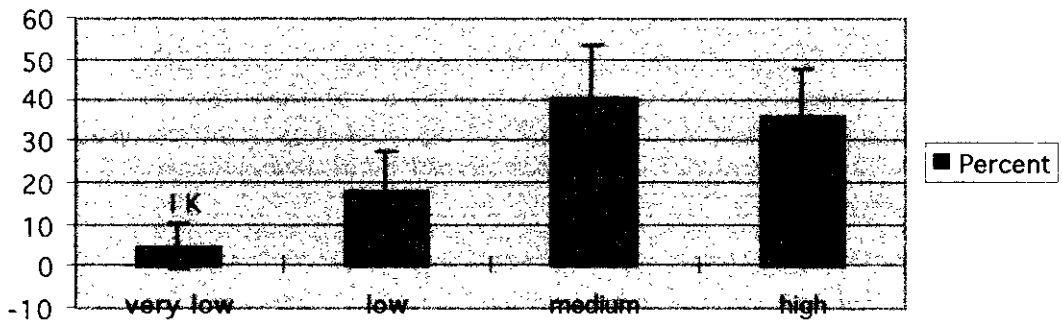
How would respondents change their practice if there were no National Curriculum?



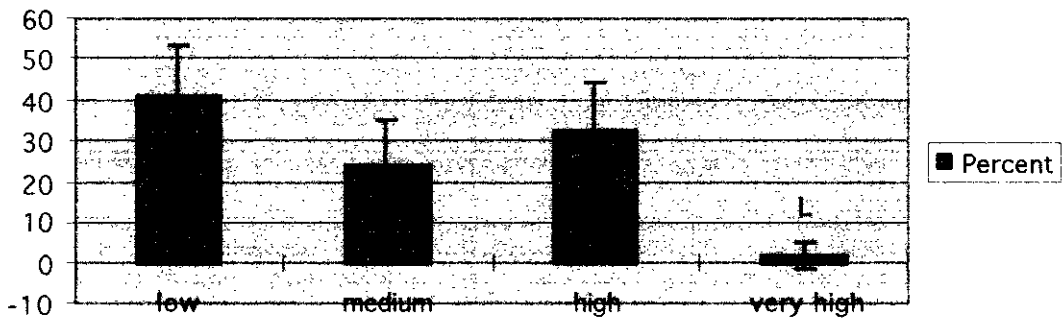
Frequency distribution for 'scientism' factor



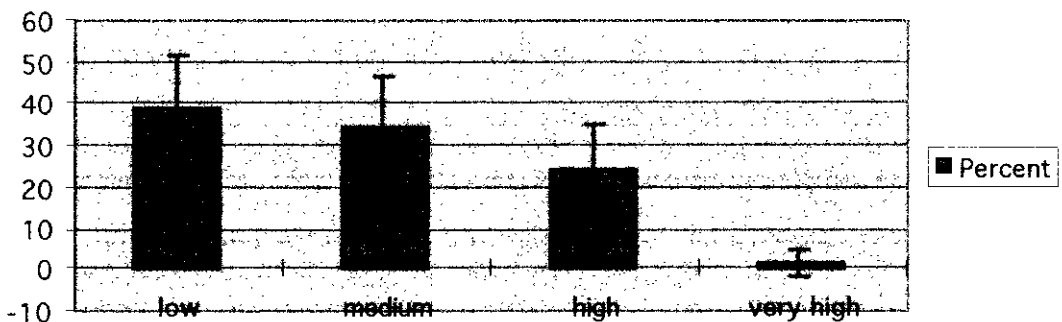
Frequency distribution for 'naive empiricism' factor

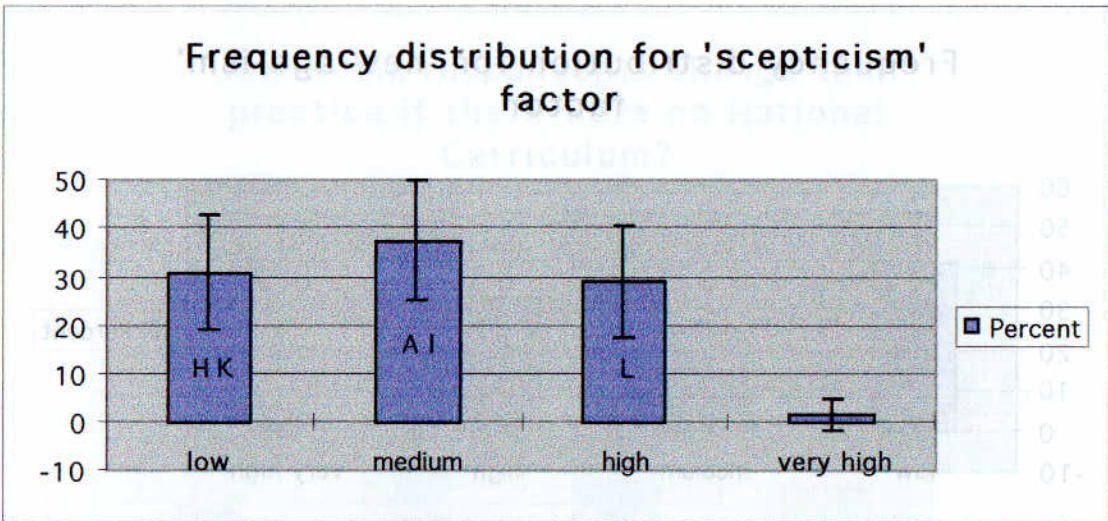
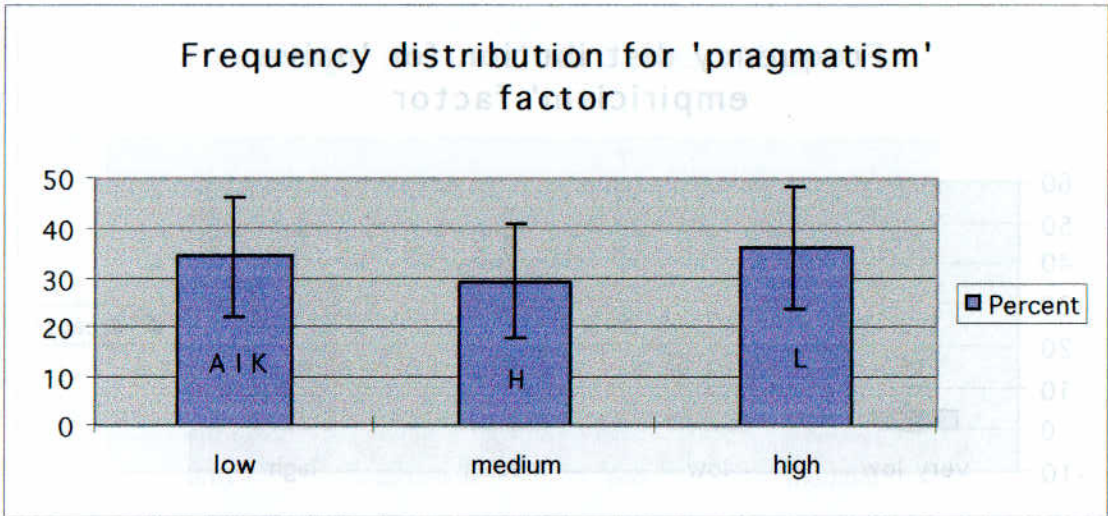


Frequency distribution for 'new-age-ism' factor



Frequency distribution for 'constructivism' factor





Again we see internal consistency in individuals' positions - Linda is clearly the most 'post-modern', new-age person, reflecting her 'arty' background and enthusiasm for new ideas: Irene's position reflects her long association with the 'nuts and bolts' of science, in nearly thirty years as a lab technician, while Keith's recent 'hard maths and physics' degree may be reflected in his responses. It will be observed that the distribution of the sample of five participants generally reflects that of the larger sample - in only one case, the distribution for the 'nature of science' factor dubbed 'naive empiricism', does the distribution of case study participants not reflect the survey distribution; and that no individual participant stands out as an extreme case, in that none regularly falls in the tails of distributions. This suggested that the case study participants would not have been atypical members of the survey sample; and to the extent that the survey sample was thought to be representative of the population of primary class

teachers, the case study participants would not have been atypical members of that population.

8.4 Triangulation between derived indicators

At a more speculative or abstract level we might look on triangulation as a means of 'getting a fix on the positions' of participants (to extend the navigational analogy). Two 'position line' sources have already been established, drawing on internally defined criteria - the match between personal theory and classroom practice, drawing on the case study data, and the survey reliability indices, drawing on survey and case study. A third source is explored below, drawing on externally defined criteria, using an entirely different perspective from which to abstract comparative indices on participants. Consistency between all three diverse sources would, it is argued, go as far as it is possible to go within this study, to demonstrate the consistency, persistence and pervasiveness of participants' professional identities.

Hargreaves and Goodson (1996, p20-21) define "seven principles of post-modern professionalism". While acknowledging the widely accepted need for technical competence and subject knowledge, they argue for a broader meaning of teacher professionalism, incorporating seven 'principles':

1. exercising discretionary judgement over teaching, curriculum and care
2. engaging with the moral and social purposes and value of what they teach
3. working with colleagues in 'collaborative cultures' to solve problems of practice (rather than engaging in joint work to implement others' solutions)
4. occupational heteronomy rather than self-protective autonomy, working with parents, children, and other stakeholders in students' learning, with authority and openness
5. commitment to active care, not just service for students, embracing the emotional as well as the cognitive dimensions of teaching

6. self-directed search and struggle for continuous learning, extending one's own expertise and practice (not compliance with externally initiated change)
7. recognition of high task complexity.

It is not part of this project's brief to judge or evaluate teachers' technical competence or subject knowledge: but the data do enable some assessment to be made of the degrees to which their practice matches these principles, albeit mostly in terms of the researcher's perception and interpretation of the data. Examples of each principle from the case studies are:

- 1 - Andrew is determined to teach science content beyond the curriculum, and to teach content through practical work throughout the curriculum.
- 2 - Irene's constant contextualisation of science content within environmental issues and green values.
- 3 - Linda's school staff as a whole spending a year of development effort on understanding progression and the incremental building of practical and intellectual skills in scientific enquiry.
- 4 - Andrew's long-term involvement with parents of ex-pupils, bringing them into the classroom, and visiting their places of work.
- 5 - Keith's achievements in 'turning round' disaffected children, through concerted and deliberate pastoral care.
- 6 - Linda's ownership of her own professional development, prioritising and focusing on mastery of each subject in turn, and gaining experience of teaching all age groups.
- 7 - Andrew seems unable to make any definitive statement about how children learn, and how best to promote that learning, without almost endless qualification, explanation, and contextualised exemplification, demonstrating his recognition of the complexity of the task of teaching.

Thus principles 1, 2, 3, 5 and 6 are addressed fairly explicitly in the case study data: 4 is assessed by inference from teachers' reports of bringing outsiders into the classroom;

and 7 is taken to be linked with degree of internal interconnectedness in personal theories of learning, though this is more speculative. In order to get a handle on the data, each teacher has been ranked from 1 to 5, where 1 is the closest match to the principle, and 5 the furthest, in the researcher's judgement, based on interpretation of the case studies.

Where it seems impossible to distinguish between teachers, they are given the same rank.

Thus:

	Andrew	Howard	Irene	Keith	Linda
1. exercising discretionary judgement over teaching, curriculum and care	1	4	3	4	2
2. engaging with the moral and social purposes and value of what they teach	2	5	1	4	3
3. working with colleagues in 'collaborative cultures' to solve problems of practice	2	5	3	3	1
4. occupational heteronomy - working with other stakeholders, with authority and openness	1	3	3	3	1
5. commitment to active care, embracing emotional as well as cognitive dimensions of teaching	1	1	1	1	1
6. self-directed search and struggle for continuous learning	2	5	2	4	1
7. recognition of high task complexity	1	4	3	4	1
total 'score'	10	27	16	23	10

This table represents the author’s codings: again an independent coder (not the same one who coded the ‘theory and practice’ comparison above), who was familiar with the case studies, came up with very similar results, and again with *identical aggregate rankings*.

This becomes interesting when placed alongside the comparisons of participants’ implementations of personal theory in classroom practice, and the independently derived survey reliability indices (see above). In all three cases Andrew and Linda are identical; Irene is intermediate, but close to them; and Howard and Keith are ‘outliers’:

	Andrew	Howard	Irene	Keith	Linda
Match between personal theory and classroom practice	3	11	5	8	3
Survey reliability indices	97.7%	94.7%	97.0%	99.2%	97.7%
Match between case study and “seven principles of post-modern professionalism”	10	27	16	23	10

The consistency within and consistent differences between case studies has already been noted, so perhaps the consistency between two very different derived indicators, relating to professionalism and to the relationship between theory and practice, while re-assuring, is not too surprising. However the consistency between these and the reliability indices, which were almost mechanically derived from comparison between participants’ survey responses and their statements and actions in teaching, planning and in interview, provide strong evidence of the reliability and validity of the case study data, suggesting the existence, persistence and pervasiveness of professional identity, in discourse and in professional action.

8.5 Reliability and Validity: Conclusions

In conclusion, the internal corroboration between data derived from different techniques within each case study, triangulation between case study and survey data, location of

case studies in survey frequency distributions, and triangulation between derived indicators, have been effective in showing that:

- each case study is internally consistent, and consistently different from the other case studies
- the survey is reasonably reliable (97% reliable overall, on 'non-factual' responses)
- the least trustworthy parts of the survey are those on issues close to the heart of the professional teacher, where a single simple response is unlikely to be satisfactory without qualification and elaboration, and which thus produces less reliable data in the survey
- the case study participants are not atypical members of the population of primary class teachers
- the consistency within and consistent differences between case studies and various disparate derived indicators, are evidence of the existence, persistence and pervasiveness of professional identity, in discourse and professional action.

9. Discussion and interpretation

9.1 The context created by the pilot study

The pilot study successfully demonstrated that it was possible, through interviews, to gain insights into how each participant had built up their professional identity as a primary teacher of science. To have an identity of this sort implies having a point of view: Harré (1998) wrote:

It is the acquisition of a point of view that is the matter of interest for the theorist of personhood, since that is one of the singularities of self expressed in personal discourse. (p13)

The pilot study touched on teachers' views of the nature of science and the purposes of teaching it in primary schools, but was more focused on participants' views of the National Curriculum and the warrants they offered for those views, set in the context of professional identities established through re-tellings of their life-histories. The teachers' science 'autobiographies' were consistent with and mutually validating of the warrants for their views on the science curriculum: with one exception they had succeeded in producing a "cognitive component of personhood" (Giddens 1991, p53) as a science teacher. Even the exception reacted to questions as might be predicted on the basis of professional action based on an identity that was distanced from science, and reacted to a situation in which having to teach science was a problematic component, by leaving teaching the following year.

Each participant complained of lack of autonomy in making curricular decisions in their own classroom; or expressed a positive desire for more freedom and time to pursue ideas that interest them and excite their pupils. These were not so much proposals for changing the curriculum in a statutory sense, as expressions of a professional urge to be free from constraints, to be the person and the teacher they feel they could be, teaching those aspects of science that they consider valuable for children. This suggested that their growing confidence in science teaching, and their wish to incorporate it into their life

experience, informed their opinions about the curriculum; and reinforced Waugh and Godfrey's (1993) finding of the importance ascribed by teachers to their participation in curricular decision-making.

All but one of the participating teachers had taken 'ownership' of science teaching in some degree, building it into their professional self-image. The resulting desire for autonomy, so often expressed in their comments on preferred content, was evidence not only of their confidence and professional identity as teachers of science, but also of their ability to provide valuable, though personal, comment on the curriculum. These comments were important not so much because we might wish to know what topics they might personally want to teach - no suggestion was made that the National Curriculum should be changed to accommodate their wishes, so there is no danger of this argument leading to the kind of incoherence and inconsistency which held sway before the curriculum was introduced - but because the very existence of a point of view which can be supported by warrants, is important evidence of the existence of developed identities as professional science teachers.

9.2 Case studies of Irene, Howard, Andrew, Linda and Keith

The main study used the same basic theory of identity, but whereas the pilot had involved a single in-depth interview with each participant, focused on their critique of the curriculum but also covering their science- and education-related life histories, and touching on their views of the nature of science and the purposes of teaching it, the main study used a series of interviews, 'think-aloud' planning sessions, and lesson observations, to focus on each of these in turn, and to look at aspects of participants' practice and their reflections on their practice. Many of the questions asked and issues discussed were quite philosophical and abstruse: that the participants were able to construct positions on such issues, when they had given little or no consideration to them before; that they were able to develop and extend such answers over an eighteen-month period, in an internally consistent way, but without remembering in detail what they had said previously; and that the questions and issues were frequently recontextualised or

redefined such that discussions could be embedded in their professional experience, suggest that they were drawing on or ‘inhabiting’ professional identities as primary teachers of science in the construction of their answers. This impression is reinforced by the kinds of warrants that they offered, which were found to draw on their personal and professional values, their personal theories of learning, their images or models of teaching, their knowledge of and relationships with children, and the images and routines that seemed to mediate at least some of their thinking about teaching - all of which are woven into or emergent from the fabric of their science- and education-related life histories.

Detailed accounts of each participant were given in the Case Studies chapter. Interesting findings from idiographic and comparative analyses of the case studies arise in relation to:

- their high degree of internal corroboration, which seems to give each case study a high level of reliability and validity
- evidence that it was the construction of a professional identity that enabled them to answer and act consistently
- significant differences between individuals, not only in terms of the substance, but also the internal interconnectedness, of their views.

These findings are discussed in more detail below.

9.2.1 Internal corroboration

The views of each participant as expressed at different times in interview, and as inferred from or implied by participants’ decisions or actions in planning or teaching, exhibited high degrees of internal consistency. This consistency within an individual’s account, and the consistency of the contrast between one individual and another, is discussed in detail in the ‘Reliability and Validity of Findings’ chapter. It provides strong evidence for the internal validity and reliability of the case studies.

9.2.2 Evidence for construction of a professional identity

Personal identity is a “structural or organizational feature of one’s mentality” (Harré and van Langehove, 1999, p7). It persists behind a publicly presented repertoire of personae, appropriate in particular contexts, and associated with coherent clusters of traits and moral positions. Both identity and persona need to be distinguished from self-concept or self-image, what the individual believes about themselves. Professional identity is taken to be a subset of or to overlap with or to be identical to personal identity - from the point of view of this enquiry it does not seem to matter which, and it may be that for any one individual, each of these may apply from time to time.

All three aspects of selfhood both shape social action and are shaped by experiences arising from social action: Woods (1984, p239-260) describes how this kind of dialectic, between teacher and subject, ‘makes’ both the teacher’s role (or repertoire of personae) and the curriculum; how the self both “finds expression in and gives expression to” the subject; and how far-reaching the effects of early experiences are in the development of a teacher’s professional identity characterized by values, dispositions and “bi-modal features” or tensions influenced by context.

Evidence that it was the construction of a professional identity that enabled the teachers in this study to answer and act consistently can be found both in their reflective comment, and in their talk and actions.

9.2.2.1 Evidence for the construction of a professional identity in reflective comment

Both Andrew and Keith, in talking about their experiences of taking part in the project, observe how they and I have talked about and around the same issues from various points of view at various times over an eighteen-month period, and how it is impossible to remember what you have said before to ensure that what you are saying now is consistent with it. Andrew describes how he has to fall back on what he calls his “general feelings” on things and how he relies on consistency with these to make the positions he constructs at various times consistent with each other. He also consciously

narrows the scope of issues we are discussing to contexts in which he can run his professional personae through familiar imagined or acted-out routines or episodes, from internal reflection on which he can abstract his answers to more general questions. Keith makes similar comments and adopts similar strategies in contextualising abstract issues, but seems to refer more to memories from childhood and teaching practice, or images based on them, rather than to images based on his current practice - perhaps reflecting his relative lack of teaching experience, and the developing nature of his professional identity.

9.2.2.2 Evidence for the construction of a professional identity in talk and actions

Evidence that the consistency in participants' perspectives was founded on their construction of a professional identity can also be found in their talk and actions. In the following, Irene is taken as an example - similar accounts could be constructed for each of the other participants.

Irene is conscious that she is still developing as a teacher, and recognises that some kinds of teacher knowledge and confidence can only develop in difficult circumstances: however, she is also aware that in 'delivering the curriculum', she has the confidence to re-make it in her own way, adding a 'green' perspective through discussion of external or social dimensions of science content, exploiting local opportunities, and helping children to engage their imaginations and enjoy their learning. Her classroom persona is brisk and kind, sardonic and respectful towards the children; and her green values are interwoven throughout her teaching, especially in the complex web of connections she creates around the content.

She sees herself as brave, foolhardy, self-sacrificing, interested in and curious about the natural world, sceptical, and especially good at "the pastoral side" of teaching, being able to empathise readily with children and others. She approaches teaching with humility, learning from and with the children, and is committed to treating children fairly, as sensitive individuals with personal rights, and with a deep and loving concern, believing

that there is nothing more valuable an adult can give a child than time - for example she sees it as the teacher's duty to lead frequent 'off task' digressions, pursuing lines of thought instigated by her or by the children. She believes that her teaching can influence the kind of people the children are growing into, by shaping their values and awareness of self and others, and helping them to become autonomous learners.

Irene's vocation for teaching is rooted explicitly in her environmental, interpersonal and social values. The oldest of and the only environmental activist amongst the five participants, her sense of her generation's collective responsibility for the state of the world impels her to a personal accountability for her contribution to the fate of the world which is evident throughout her planning, teaching and reflection.

9.2.2.3 Professional identities as primary science teachers

Woods' view of the dialectic between teacher and subject creating both the teacher's professional personhood, and the curriculum as embodied in the teacher's practice, is thrown into interesting relief by the context of the primary teacher, who may have to teach up to ten subjects and who is increasingly constrained to teach them as discrete subjects rather than woven together in a topic-based approach. The old tag 'primary teachers teach the child, not the subject' takes on new depth in this context, as we note that an unquantifiable but significant part of the teachers' values, and the personal theories of learning that underpin their professional identities, are not specific to science, but may be applicable across a range of subjects. Not much can be said about this here, as the focus has been on primary *science* teaching throughout, beyond observing that it is not clear to what extent the professional identities inferred from this work are subject-specific, and to what extent they are generic.

9.2.3 Internal interconnectedness

Though the origins of the connectionist or network model can be traced back through Wittgenstein and Whitehead to Leibniz, it did not show signs of gaining its current ascendancy until the last few decades of the twentieth century. Then, areas as diverse as operational research, artificial intelligence, and systems theory on the one hand, and

sociology, psychology, ecology and neuroscience on the other, began to encounter problems and devise intellectual tools for understanding them, such that network theory was a pre-requisite: and it became one of the central, most prevalent metaphors of our times (Lehmann, 1992). Its rise has been paralleled by a growing recognition of the centrality of the concepts of agency and identity in understanding personal and social being and action (e.g. Harré, 1979, 1983, 1991; Giddens, 1991; Taylor, 1985).

Ausubel (see e.g. Ausubel and Robinson, 1969) incorporates both agency and connectivity into his distinction between two dimensions of learning - the reception/discovery dimension, which indicates the degree of transformation required to accommodate something; and the meaningful/rote dimension, which refers to the level of connectedness with prior knowledge, of what is learnt: meaningful learning only occurs when the learner makes sense of what is learnt by relating it to what is already known. Biggs (1980) distinguishes surface (isolated, unconnected, inflexible) learning, and deep learning, with richly connected ideas, which may be 'elaborated' and whose connections may be adjusted and multiplied by reflection, moving them to another (more effective) place in some internal cognitive hierarchy or network. Bereiter and Scardamalia (1998) describe seven 'levels' of knowledge, from the "individuated mental states" of young children, through itemizable mental content, knowledge as representation, and knowledge viewable from different perspectives, to knowledge as personal constructs, as *improvable* personal constructs, and as "semi-autonomous artifacts". Taken together, these perspectives reinforce Ausubel's identification of two dimensions in relation to which areas of a person's knowledge can be located, viz.:

1. in relation to connectedness: from the disjunct, unstructured, potentially contradictory, "surface", to the coherent, meaningful, richly connected and contextualized, "deep"
2. in relation to agency: from the received and applied as is, to the transformed and renewed through practice; and from the known, to the "meta-known", open to reflection, elaboration, re-connection, improvement.

The teachers in the study varied in the degree of internal interconnectedness in their thinking, as evidenced by the relative ease (or otherwise) with which the various strands in their thinking could be isolated; and in relation to the degree of autonomous agency that they brought to their professional development. For example:

- When probing Andrew or Linda's personal theories of learning, or Andrew's views on the nature of science, the richness of internal interconnection was such that it was impossible to isolate any aspect without extensive qualification; and each seemed to move between the abstract and the contextualized with great fluency. The theories of learning of Keith, the least experienced of the participants, seemed terse and disjunct, perhaps being remembered from his training a few years earlier, but not yet transformed through experience into the knowledge of a professional practitioner.
- Linda's commentary on her own professional development suggested that she was exercising autonomous agency in her determination to teach all year groups, and in her shift of focus from English and maths (which she felt she had 'mastered') to science and D&T (which she was predicting would take her two years to master, where mastery includes confidence in one's competence, being unembarrassed by one's areas of ignorance, both 'macro-' and 'micro-knowledge' of progression, and a deep integration of the various areas of the curriculum). Irene too is aware of developing professionally, though seeing this as more a product of classroom experience than of a personal focus. Howard, though younger than Irene, has been teaching for much longer: he feels he is barely able to cope with externally initiated change, and is too old for further professional development.

It may be argued that the degree of internal interconnectedness in a teacher's thinking, and the degree of autonomous agency that they bring to their professional development, are useful indicators of their development of a professional identity; and that the greater the degree of internal interconnectedness of the network, the greater the stability and integrity of that identity.

9.3 The survey

In addition to the five case studies, a larger group of primary teachers was surveyed. In addition to general biographical and professional information, the survey covered aspects of:

- their professional views on teaching in general
- their professional views on primary science teaching, including the science curriculum and the purposes of primary science education
- their concerns about their science teaching
- their views of the nature of science.

The purpose of conducting the survey was two-fold:

- to check the external validity of the case studies; and
- to allow estimates of the distribution of particular views and positions in the wider population of primary teachers.

The ‘Reliability and Validity of Findings’ chapter describes how the external validity of the case studies is verified by the survey, by demonstrating that the case study participants are not atypical of the survey respondents in any consistent way; and how triangulation between survey and case studies, based on the fact that the teachers who participated in the main study also completed the survey questionnaire, gives a ‘reliability factor’ of 97% over all the non-factual questions in the survey. The substantive findings of the survey in relation to the views and positions of teachers have been reported in detail in the Survey Results chapter. Points of particular interest are that:

- they feel relatively comfortable with teaching science, compared to other subjects
- their views of the nature of science vary widely
- their views on the role of subject knowledge in science teaching vary widely
- their main concerns are resources, and explaining concepts at the children’s level

- most believe they could improve their science teaching, especially in relation to ‘scientific enquiry’
- most bring discretionary science content with an environmental focus into their classrooms
- there is no overwhelming push for radical change in curriculum or practice
- the more comfortable they are in teaching science, the higher their level of support for environmental groups is likely to be, and the more ‘connectionist’ a view of learning they are likely to have.

9.4 Triangulation between survey and case studies

The teachers who participated in the main study also completed the survey questionnaire, which enabled the reliability and validity of the survey, and the external validity of the case studies, to be assessed. As described in the ‘Reliability and Validity of Findings’ chapter, it was found that:

- the case studies are internally consistent and consistently different, suggesting that they provide internally valid and reliable data
- the survey is reasonably internally reliable, and internally and externally valid
- the case study participants are not atypical members of the population of primary class teachers, suggesting that the case studies provide externally valid data
- the case studies suggest the existence, persistence and pervasiveness of professional identity, manifest in discourse and professional action.

9.5 Professional identities - a hypothetical model

‘Freud was wrong.. it is not painful memories that are repressed, but those inconsistent with our current self-image.’ Chris Heron, New Scientist, 1 July 2000

Andrew and Linda appear to have well-developed professional identities as primary science teachers. Founded on a limited number of very positive images of science teaching from their own school-days, and developed through personal autonomy and collegial interaction, these identities are functional, dynamic, reflexive, and continually self-recreating through practice - and most importantly, seem to run through everything they do. Both argue in interview and, by their own accounts, in the staffroom, for views that may be unpopular or not 'politically correct', and exercise autonomy in carrying their views through into their teaching; yet both interact heteronomously with the collegium within their schools, and with parents and outsiders.

Irene and Keith seem to be in the process of developing professional identities, and Irene seems to be further along than Keith, with more experience, driven by an intense vocational commitment, and aided by her familiarity with science process arising from her long-term contact with science as a lab technician. Keith's values and vocational commitment are elsewhere; he feels insecure in his knowledge of the life sciences area; and he resents the constraints on his teaching created by the national assessments in Y6. Factors such as these may create tensions which hinder the development of professional identity - certainly in the warrants he gives for his views he draws almost exclusively on his own schooldays and his experiences in teacher training, rather than his classroom experiences since qualifying.

It is hard to avoid the conclusion that Howard's professional identity is in some ways dysfunctional. His memories of school and his reasons for entering teaching show a propensity for taking the soft option; he complains of having had both too much and too little in-service training relating to physical science; his theories of learning and ideas about science teaching are sparse and disjunct, and correspond only slightly with his observed teaching; his survey answers are the least reliable; and his focus is on personal survival rather than professional development. (This is intended to be a disinterested account, not a harsh judgement on Howard, who is, in a sense, trapped by his past and his present. His own primary education provided him with no models of teaching beyond "good, solid" transmission. He chose a teaching career almost by default. Since

1970 he has had to cope with a series of radical changes that amount to changes in polarity, in what is required of him as a primary teacher. For many it has been a struggle, and for Howard it has become almost too much. He is hanging on, surviving, but has exhausted his ability to remake his identity: he works in a state of great tension, but feels impotent in the face of the constraints that bind him. Yet despite this, he takes the lead in science amongst the three Y3 teachers, and seems to retain both a rather desperate self-belief, and the respect, or at least the indulgence, of his colleagues.)

A hypothetical model suggesting a partial explanation for some of these findings is outlined below:

Professional identity is constructed through action, discourse and reflection, and through a dialectic between the emerging identity and the experiences of teaching and being a teacher. It is an emergent entity arising alongside increasingly autonomous or heteronomous agency and in the increasingly rich network of connections between knowledge, beliefs and values in several areas, including: life history; relationships with children and with colleagues; teaching and learning in general and in science; curriculum, subject and pedagogic knowledge; self-image; and science teaching practice. It arises over a period of several years, and may pass through threshold or step changes with concomitant changes in confidence, effectiveness, and reflexive awareness. It is dynamic in that all parts of the network change over time, and connections need continually to be re-evaluated, adjusted and recreated. It is functional in that it orchestrates personae and deployment of routinised scripts and actions, and that it enables new problems and issues to be dealt with in a way that draws on the whole network that underpins it. It can also be dysfunctional.

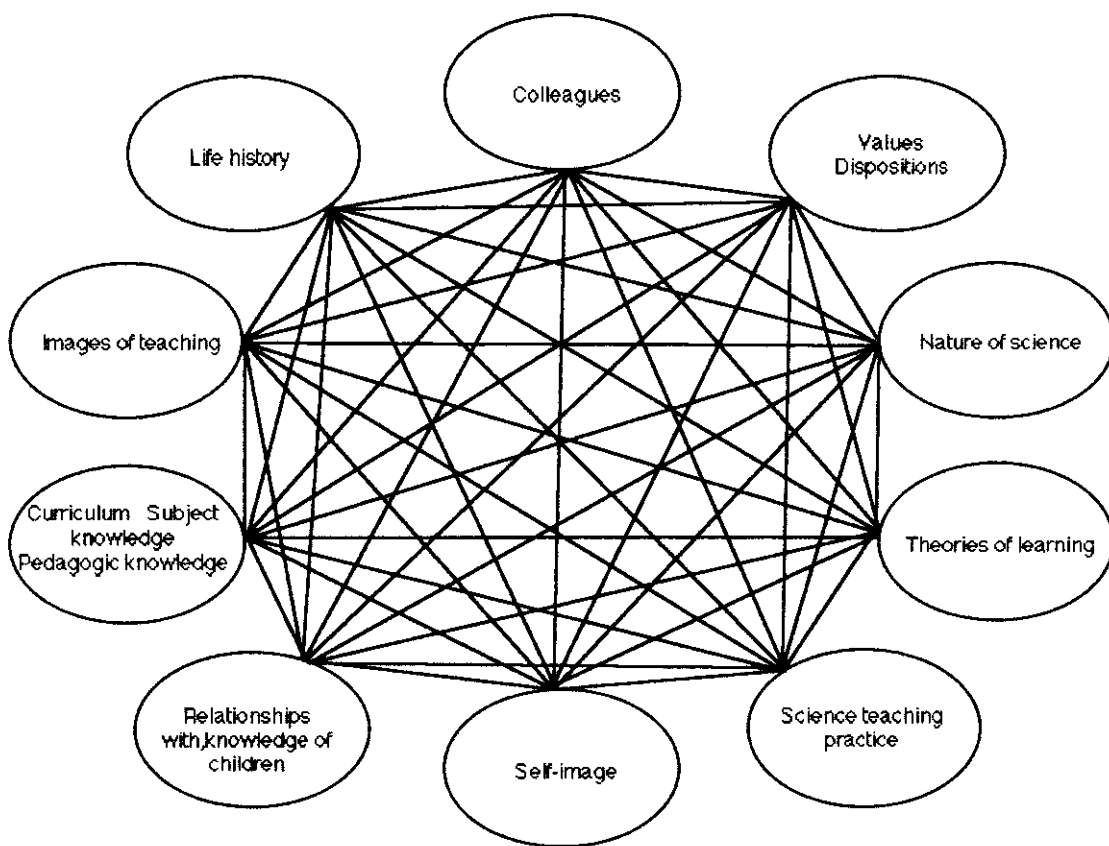


Figure 1: Professional identity - 'components' and 'precursor network'

At the inception of the idea of becoming a teacher, there is an agent, with a personal identity and life history which are constantly remaking themselves, and with an intention, which immediately becomes part of the remaking processes. To begin with various areas of knowledge and belief, and connections between them, are built up, recreated, reconnected. Perhaps parts of this network coalesce into context-sensitive positions around images like Keith's memories of the 'conditions for growth' investigation in his second teaching practice, which go on to further levels of organisation: perhaps multiple candidate identities arise and evolve through some selective process; or perhaps there is one big 'gloop' - think of a combination of gravitational collapse, compiling a computer program from source to machine code, or learning to drive a car - in which a very complex network is greatly simplified by the emergence of a professional identity which mediates and 'meta-connects' all connections:

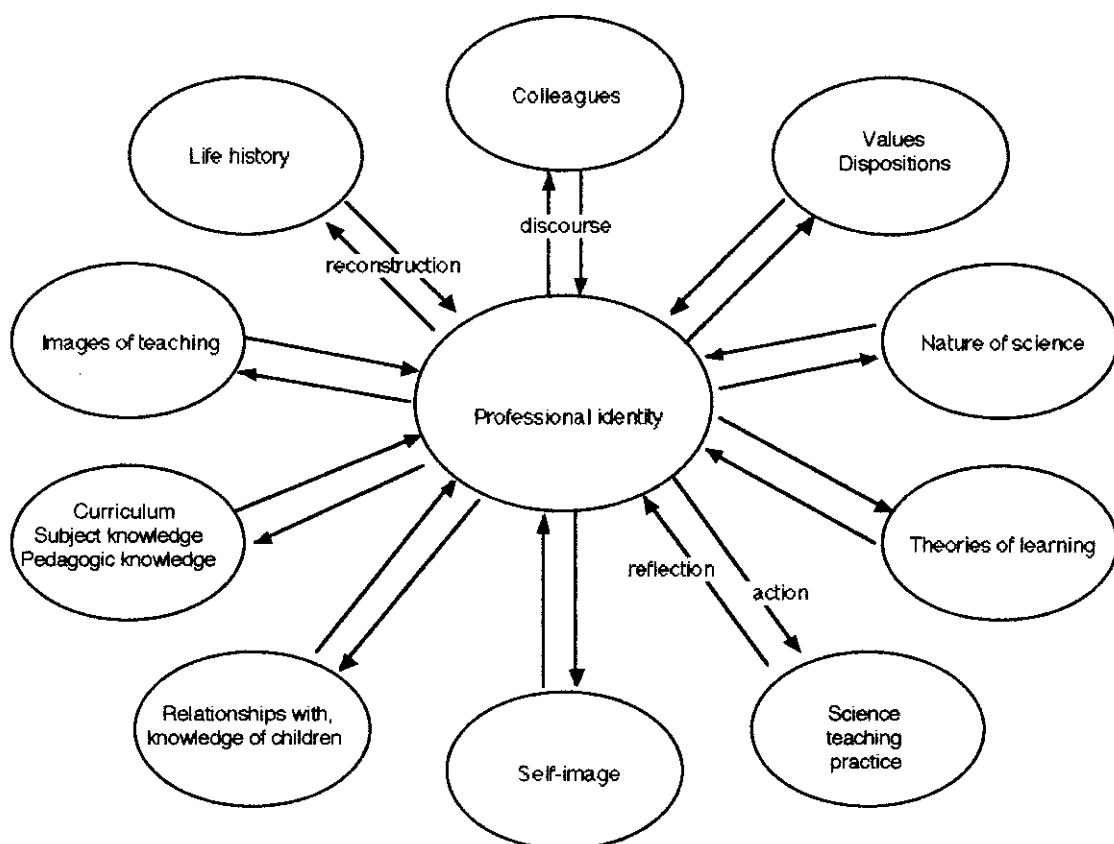


Figure 2: Professional identity, emergent from precursor network

The dynamism of the professional identity arises from its own constant recreation, through the recreation of the contributing areas of knowledge and belief, and through constant reflection on and recreation of the connective network that it subsumes.

The professional identity has an 'agency' as well as a 'connectivity' dimension, which is manifest in autonomous and heteronomous action, and in reflection.

In the context of this project it is argued that the professional identity enabled participants to answer difficult questions, which were both abstract and abstruse, and which they had not seriously or systematically considered before - questions like:

- Does scientific knowledge have a special status, compared to (say) historical, literary or religious knowledge?
- Is scientific knowledge created or discovered?
- Is there a relationship between how children learn science, and how scientific knowledge itself is created or discovered?

- Are electrons real?
- What's the relationship between science and morality?
- How does scientific knowledge change? Does it always change for the better?
- Where do scientific theories come from?

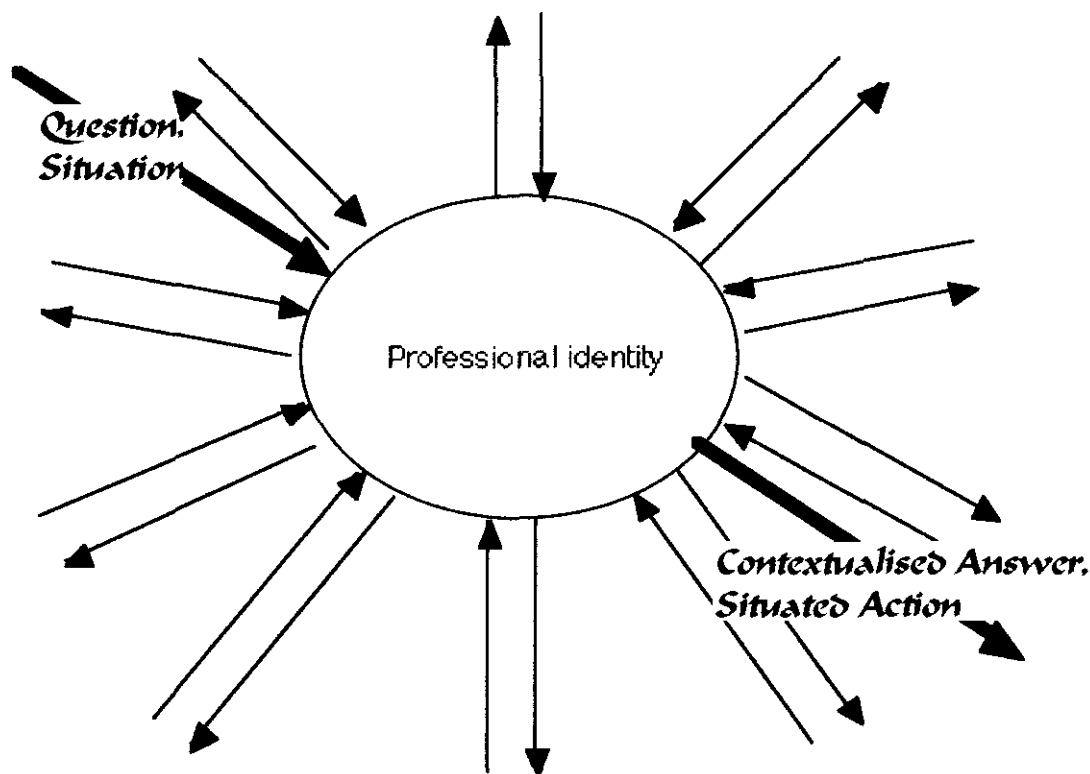


Figure 3: Mediating between question and answer, problem and solution

All elements in the model and all the processes involving them are created and continually recreated in shifting cultural settings: so for example an autobiography is constructed from selectively remembered episodes which were themselves situated in what now might seem the rather remote cultural settings of the teacher's childhood home, classroom and school cultures.

Similarly, on-going re-construction of autobiography, the collegial discourse between teachers in a school staff, and so on, are situated in relation to various cultural contexts, such as the classroom culture (re-)created in the teacher's own classroom, the peer-to-peer culture of the staffroom, and the wider school culture involving management, parents and beyond: all the processes contributing to the on-going reconstruction of identity are similarly culturally situated.

The model also shows possible ways in which things can go wrong:

- The identity may be more or less lacking in integrity.
- Positive feedback between low self-esteem, selectively recalled negative memories, fear of disapproval from colleagues and children, insecure subject knowledge, and poor teaching experiences could perpetuate a cycle of perceived failure.
- A dearth of strong values and a lack of engagement with the nature of the subject matter and with one's own beliefs about learning could lead to practice that is perceived by the teacher him- or herself as unsatisfactory before, during and after execution.
- The professional identity exists and is constantly recreated within a number of cultural contexts, some of which could themselves be dysfunctional, or dysfunctionally related to the identity - for example a school culture dominated by a discourse of performance assessment, league tables, naming and shaming, failure, excellence, and a promised future of ever-increasing struggle, might not provide the optimum situation for an identity already burdened by low self-esteem and insecurity.

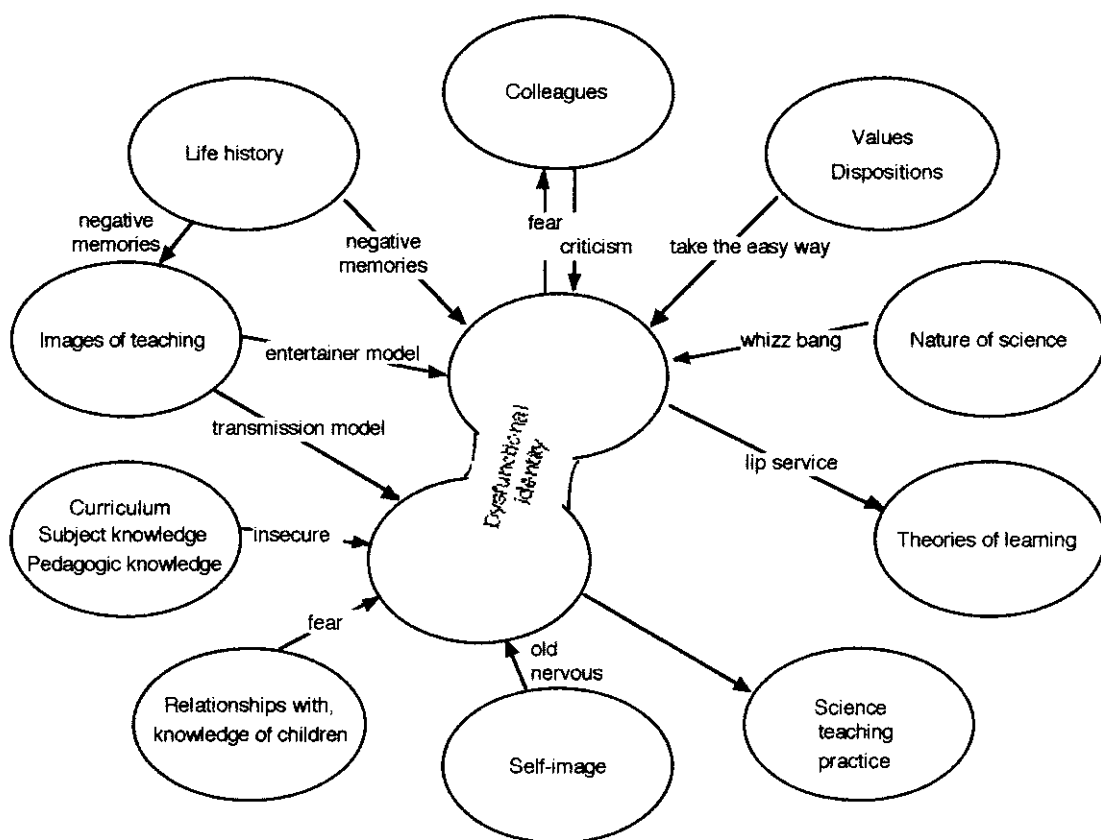


Figure 4: Hypothetical model of example of dysfunctional professional identity

Other factors in dysfunction could include the kinds of tension and constraint arising from being ‘forced’ to teach in a mode that is ‘alien’ to one’s developed or developing identity, as Linda was in her first school after qualifying, through pressure from the head teacher; or as Irene and Keith are, in the way in which KS2 SATs shape the whole of their work in Y6.

9.6 Answering the research questions

‘A single purpose can be fashioned from a jumble of opposites.’ Louis MacNiece

The findings of this research are on two levels: the substantive level of teachers’ views of the nature of science, their perceptions of their experiences of science teaching, and so on: and a more abstract level, where an explanatory framework for some of the substantive level findings is proposed, based on an emergent professional identity. Findings at the substantive level, it is claimed, have been shown to be reliable and valid: findings at the higher level are more speculative but perhaps potentially more important.

The research questions are not such as to admit of a nice, short, tidy answer. The fullest account of answers found by this study to questions 1, 2, 3, and to some extent 4, are embedded in the rich descriptions of the case studies, the details of the survey results, and the discussion of triangulation; while some of the more salient points are articulated in the preceding discussion. The following gives a summary of the kinds of answers found.

Q1. How do primary teachers perceive their personal experiences of science; their personal experiences of science education; the nature of science; primary science education; and themselves as primary science teachers?

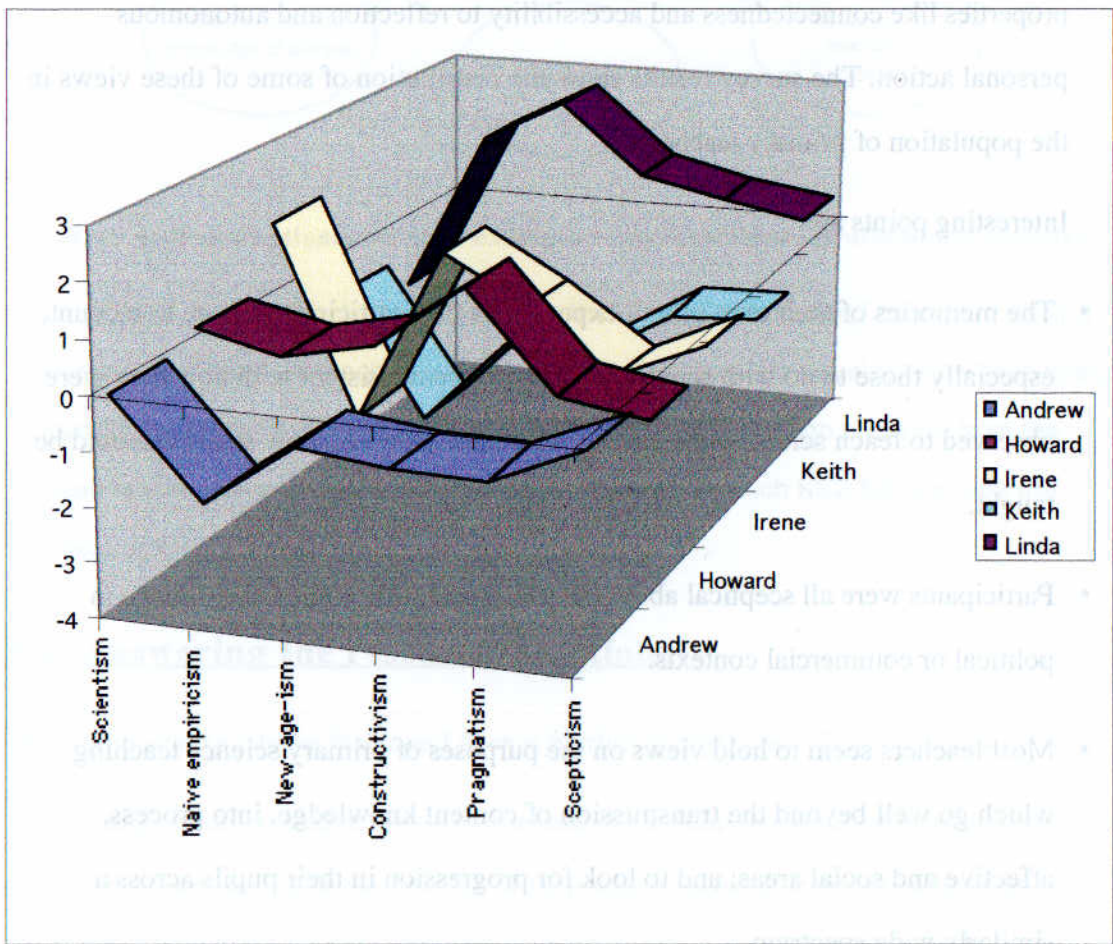
A: In ways that vary from one to another, both in substance and in meta-level properties like connectedness and accessibility to reflection and autonomous personal action. The survey results show the distribution of some of these views in the population of primary teachers.

Interesting points are:

- The memories of their own school experiences that participants chose to recount, especially those to do with science learning, were consistent with how they were observed to teach science now, and/or with their views on how science should be taught.
- Participants were all sceptical about the use of scientific claims as evidence in political or commercial contexts.
- Most teachers seem to hold views on the purposes of primary science teaching which go well beyond the transmission of content knowledge, into process, affective and social areas; and to look for progression in their pupils across a similarly wide spectrum.
- Being comfortable with teaching science seems to be associated with a connectionist view of learning, and sympathy with environmental pressure groups.

- The survey suggests that most primary teachers are comfortable with teaching science, on average ranking it fourth out of ten subjects in this regard; most bring extracurricular science with an ‘environmental’ flavour into their classrooms; and most see better teaching of science content through practical work as the way in which they could best improve their own science teaching.

The ‘nature of science’ part of the survey identified six factors explaining over 80% of the variance in the sample. The factors, defined by weightings on a series of issues, were tagged as ‘Scientism’, ‘Naive empiricism’, ‘New-age-ism’, ‘Constructivism’, ‘Pragmatism’, and ‘Scepticism’. The case study participants’ profiles on these factors are shown below.



Case study participants’ scores on ‘Nature of Science’ factors

Andrew’s thoughtful and cautious view of science as expressed in interview seems to represent a reasoned integration of a spectrum of philosophical positions, including

Kuhn and acknowledging relativism, but resolving into a kind of modest realism tinged with humility: his survey results show most sympathy for scientism and scepticism, strong rejection of empiricism, and more moderate objections to the remaining factors. Keith shares the same sort of pattern, but is more negative across the board, reflecting his commitment to religious absolutes which imply rejection of much recent philosophy of science. Irene too rejects empiricism, but holds in parallel an enthusiasm for science and a ready scepticism. Howard emphasises the human construction of theory, and its tentative nature; while Linda's enthusiasm for process, and her extensive background in the arts, seem to lead to a philosophical eclecticism and pluralism.

Overall the survey and case studies offered support for the initial hypothesis that primary teachers' understandings of the nature of science would affect their attitudes towards science and science teaching, and perhaps also the images of science they communicate to their pupils; and that individual teacher's understandings of the nature of science seem to draw on a variety of sources of experience and sometimes rather remote connections with philosophical traditions.

Q2. What views of the nature of science and of science education are manifest in primary teachers' approaches to planning and teaching a science unit or topic? Do such views appear to change or develop following in-depth discussion of these subjects?

A: The views that appear to be manifest in planning and teaching seem to overlap to a large degree with those expressed in interview, with some differences and additional views, as described in the individual case studies.

Interviews probing individuals' views of the nature of science showed them to be complex, pluralistic and context-sensitive, drawing on a range of sources from, and being reinterpreted through, personal and professional experience, suggesting that their views of science education may be produced by or developed in the dialectic between personal identity and teaching in which professional identity is forged, and are deeply imbued with and shaped by teachers' values and their science- and education-related life histories.

Little evidence was found in protocol analysis or observation to suggest that in-depth discussion of the nature of science and of science education leads to radical or even readily detectable changes in teachers' views, though in reflective comment in interview, some were aware of subtle changes in their own views, for example both Andrew and Linda felt more confident of or comfortable about their own uncertainties in relation to philosophical issues in science, perhaps reflecting the rich interconnectedness of their thinking, and the stability that might be expected in such a richly interconnected network. Other reflective comments on changes to participants' thinking over the eighteen months of the project were to the effect that:

- Linda felt our discussions had helped her focus on the need for children to understand *why* they were doing something; the importance of reinforcing the home-school link through shared activities; and the need to connect science with the rest of the curriculum, and the curriculum with children's lives, making their learning emotionally, cognitively and culturally meaningful to them. These changes were not limited to her science teaching, but had 'filtered through' into other subjects.
- Irene found that taking part had helped her develop her reflective capacity and self-awareness, and had led her to rethink her views on the moral aspects of science. Thinking differently about her practice may have led to changes in it, though she cannot identify anything specific.
- Andrew felt he had become more interested in, but less dogmatic about, some of his ideas about science; and had become more convinced of his established approach to science teaching, specifically mentioning the pre-eminence of practical work, the need to accommodate the different needs of different children, and the merit of exploring the knowledge children bring with them, not in order to change it so much as to better connect what you are teaching into it.
- Howard and Keith specifically deny any change in their views, their thinking or their teaching as a result of our conversations.

Q3. What kinds of warrants are offered in support of their views? Do they give any indications of the ontogeny of their views; of the kinds of knowledge being deployed; of the stance from which the view is being offered (having implications for identity)?

A: Warrants draw on personal history, self-image and values; classroom experience; personal theories of learning; reflections on teaching in general, and on science teaching; perceptions of contingent tensions and constraints; perceptions of the nature of science; and relationships with children and with colleagues.

The ontogeny of views, the kinds of knowledge being deployed, and the stance from which the views were offered, varied within and across teachers: there is some evidence that the least experienced was using what he had been taught in ITT, more-or-less untransformed by practice, alongside school and college memories, and a personal identity rooted outside teaching; while for the more experienced, warrants based on practice, situated knowledge, and professional training transformed through practice, were mediated by developed professional identities as primary science teachers.

Q4. Is it possible to describe the nature of professional identity in these teachers, and how science teaching is accommodated into it?

A: Evidence for the existence, stability and nature of participants' professional identities as primary teachers of science is adduced, and a hypothetical account of its ontogeny is sketched above, based on its emergence within a limited range of cultural contexts from a richly connected network of moral, emotional, cognitive and cultural entities, processes and relationships. This account attempts to show how the various elements associated with teaching science - curriculum knowledge, subject knowledge, pedagogic knowledge, theories of learning, knowledge of children, memories of being taught science and other subjects, models of teaching, the experience of and reflections on practice itself, and so on - are accommodated into the emerging identity, and how certain possible dysfunctions might arise.

Looking back to the literature review, there are a few specific points that this project failed to confirm in relation to primary teachers, viz.:

- Brickhouse's (1991) finding, in relation to secondary science teachers, that their views of how scientists construct knowledge are consistent with their beliefs about how students should learn science;
- Koulaidis' (1987) finding, again in relation to secondary science teachers, that they tend to consider theoretical entities as 'real';
- Koulaidis and Ogborn's (1989) finding, again in relation to secondary science teachers, that they can be positioned as 'naïve inductivists', or located in any other simple category;
- Pomeroy's (1993) negative correlation between holding 'non-traditional' views of the nature of science and the number of science courses taken.

In all cases, though these findings might apply to one or two participants in this study, they did not seem to be generally applicable.

Again looking back, this time to the list of problems and hypotheses outlined in the 'focus and rationale' section of the research questions chapter, it seems that most of the issues raised have been addressed by the research. The hypotheses have been to a greater or lesser extent confirmed, albeit in qualified ways, as discussed above, in relation to primary teachers' perceptions of the nature of science, the purposes of teaching it, progression, the curriculum, the influence of the teacher's science- and education-related life history, and the reflexive relationship between views of the nature of science and the experience of teaching it (hypotheses i, ii, iii, iv, v, vi, and viii). In relation to hypothesis vii, *'that teachers will vary in their perceptions [of the nature of science] and professional practices [in science teaching], and that these variations may be related, e.g. to the extent that a teacher sees science as a body of knowledge, they may see the purposes of primary science as building up pupils' science knowledge, and progress in terms of accumulated facts; whereas a teacher who sees science as a way of finding out may see purposes in terms of problem-solving, experimental design and discovery, and look for progress in*

terms of the cultivation of disciplined curiosity or asking good questions', perhaps the best that can be said is that there does seem to be a relationship, but that both terms in it - perceptions of the nature of science, and professional practices in science teaching - are more complex, and the relationships between them more subtle, than the examples suggest.

A tentative suggestion derived from this research, which goes beyond the hypotheses and research questions, relates to the timescale in which science teaching may become part of professional identity, or in which significant changes in the science to be taught may be accommodated. For many teachers, such an accommodation took place in the years following the introduction of the National Curriculum. The findings of Wragg et al (1989), Bennett et al (1992), and Harland and Kinder (1997), relating to that time, are consistent with the tentative suggestions derived here: that the timescale for accommodating science teaching into identity and practice, for beginning to teach with confidence and personal conviction, may at least in some cases be of the order of three to five years; and that this change may be forged through teachers' own personal experiences of teaching, in which the network of connections between all the contributing areas of knowing and acting, discourse and experience, is enriched and reorganised until it goes through the kind of threshold change which produces a new professional identity.

9.7 Implications for policy, practice and research

9.7.1 Curriculum reform

The model of 'professional identity' suggests the paucity of the 'delivery' and 'transmission' metaphors; and suggests how in contrast the curriculum is recreated in the classroom through the medium of the teacher's professional identity and all that constitutes it - only through a dysfunctional identity will the process bear any resemblance to 'delivery'. Teaching appears to be a very personal and creative process (as learning may be, for the pupil) in which their personhood is constantly recreated in

action and in context. The model may help policy-makers develop an approach to curriculum reform, and to change in education in general, that reflects the complex and personal nature of classroom reality, rather than the mirage of the 'delivery' of the curriculum, the 'transmission' of knowledge.

A sine qua non of such an approach would be to take the necessary steps to find out what kinds of reform and what avenues of possible improvement teachers themselves can see. The survey results give an indication of the kinds of thing that might be found were this to be done on a large scale; and it is interesting to note that the kinds of change that the survey, carried out in early Spring 1999, suggested teachers were looking for - for example more flexibility to allow contextualisation of content in relation to children's experiences outside school; finding ways of teaching content through practical work and *vice versa* - had much in common with the kinds of change that were in fact introduced in the revised curriculum published by DfEE and QCA in September 1999.

Solomon (1987, p74) wrote in relation to change in secondary science, that "a whole science department should plan together for change. The significant unit is no longer the single teacher". The model suggests that also in primary schools, change that does not involve the collaborative efforts of all staff is unlikely to reach into all their professional identities and be recreated in their teaching. This complements Harland and Kinder's (1997) comments on the failure of the 'cascade' model, and the centrality of values developed and deployed in the teaching process.

9.7.2 Professional development

The model suggests that professional development is roughly equivalent to development of professional identity. This makes it clear that it is the responsibility of each individual teacher, autonomously; and the collective responsibility of each group of teachers, heteronomously. It also suggests that it involves or could involve learning, action and reflection in relation to all the elements in the model, including autobiography, collegial discourse, relationships with children, and personal theories of learning, as well as elements like subject knowledge which may be more often encountered in this context.

The highly personal nature of the professional identity suggests that some sort of professional development counselling, and personal 'portfolio' building, might be called for, at the individual level; and perhaps equivalents at the group level.

9.7.3 Subject specialisation

In a transmission model of teaching and learning, nothing could be more natural than using subject specialists as far as possible. In a connectionist, social constructivist, discursive psychological or cultural psychological model of teaching and learning, on the other hand, in which the teacher recreates the curriculum in personal action, through their professional identity and in relationship with the pupils, and connects with pupils' experiences inside and outside school, and their learning across and beyond the curriculum, subject specialisation is clearly counter-productive - as Irene says, the benefits of the single class teacher in primary school may far outweigh any problems of patchy subject knowledge, because of the importance of the teacher's knowledge of the children, their homes, interests, strengths and weaknesses, and of the teacher's knowledge of and *personal investment* in their learning across the curriculum, and their developing personhoods.

9.7.4 Implications for research

Possible directions for future research might include verification and elaboration of the model of professional identity, especially its developmental and dynamic aspects, and the role of agency. Capra's (1996) synthesis of strands of systems, complexity, and ecological theory may give a steer on what kind of thing to look for, which may include characterisation of the emergent identity as a process rather than an entity; and emergence of the identity from networks of processes and entities that have both structure and organisation at multiple levels. It may be that we come to see Shulman's analysis as primarily addressing the issue of structure: and life history work, and idiographic studies such as this, as tentative early steps towards understanding the patterns of organisation and the processes of autopoiesis or self-making through which identity is constantly recreated.

Other possible additional or complementary ways forward might include:

- Exploration of other subject areas in general primary practice, and subject specialists in primary and secondary contexts, using a similar methodological approach.
- Application and testing of the model in understanding various phenomena and problems - for example from this project, the apparent P.E. - Science axis, or the preponderance of 'green' sympathisers, found in the survey.
- Investigation of the dialectical relationships between the various elements of the model - for example between the professional 'college' within the school, and the professional identities of the individual teachers within it.
- The survey suggested that many primary teachers, perhaps around 70%, are bringing contemporary and topical science into their classrooms, and striving to connect science with children's lives, environments, and the technology they encounter in them - the question arises as to whether some 88,000 people are independently re-inventing something very similar to the STS (Science, Technology and Society) initiative (Solomon, 1993), in thousands of schools across the country, and if so, whether there is a more efficient way to do it.
- It may be possible to investigate relationships between teachers' development of professional identity, and the learning and personal development of children in their classes.

In a sense this project's use of an explanatory paradigm involving identity, network and agency, which has not yet been widely applied in education but which is becoming widespread elsewhere, suggests that there may be scope for further work beyond the examples sketched above.

References

- Abrams E, Wandersee J (1995), *How does biological knowledge grow? A study of life scientists research practices*, Journal of Research in Science Teaching 32(6) p649-64
- Akerson VL, Abd-El-Khalick F, Lederman NG (2000), *Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of the nature of science*, Journal of Research in Science Teaching 37(4) p363-385
- Alexander R, Rose J, Woodhead C (1992), *Curriculum organisation and classroom practice in primary schools: a discussion paper*, London, DES
- Appleton, K. (1995), *Student teachers' confidence to teach science: is more science knowledge necessary to improve self-confidence?*, International Journal of Science Education 17(3) 357-69
- ATL (1996), *Doing our level best: an evaluation of statutory assessment in 1995*, London, Association of Teachers and Lecturers
- Ausubel DP, Robinson FG (1969), *School Learning: an introduction to educational psychology*, New York, Holt, Rinehart and Winston
- Ayala F J, Dobzhansky T (eds) (1974), *Studies in the Philosophy of Biology*, London, MacMillan Press
- Ball SJ (1984), *Beachside reconsidered: reflections on a methodological apprenticeship*, in Burgess (ed) (1984), *The research process in educational settings*, Lewes, Falmer
- Ball SJ, Goodson IF (1985), *Understanding teachers: concepts and contexts*, in Ball SJ, Goodson IF (1985) (eds), *Teachers' lives and careers*, London, Falmer
- Bennett, N. (1976), *Teaching styles and pupil progress*, London, Open Books
- Bennett SN, Wragg EC, Carre CG, Carter DSG (1992), *A longitudinal study of primary teachers' perceived competence in, and concerns about, National Curriculum implementation*, Research Papers in Education 7(1) March 1992
- BERA (1992), *British Educational Research Association Ethical Guidelines*, Edinburgh, British Educational Research Association

- Bereiter C, Scardamalia M (1998), *Beyond Bloom's Taxonomy: rethinking knowledge for the knowledge age*, in Hargreaves et al. (eds) (1998), *International Handbook of Educational Change, Part Two, Section 3: Fundamental Change*, p675-692
- Bertaux D (1981), *From the life-history approach to the transformation of sociological practice*, in Bertaux, D. (ed) *Biography and society: the life-history approach in the social sciences*, Sage. Newberry Park, California p29-45
- Bertaux D (ed) (1981), *Biography and society: the life-history approach in the social sciences*, Newberry Park, California, Sage
- Bhaskar R (1989), *Reclaiming reality: a critical introduction to contemporary philosophy*, London, Verso
- Biggs J (1980), 'Developmental processes and learning outcomes', in Biggs, J. and Kirby, J. (eds) (1980), *Cognition Learning and Instruction*, New York, Academic Press
- Bishop K, Denley P (1997), *The fundamental role of subject matter knowledge in the teaching of science*, *School Science Review* 79(286) p65-71
- Blau P (1975), *Approaches to the study of social structure*, New York, The Free Press
- Bliss J, Monk M, Ogborn J (1983), *Qualitative data analysis for educational research*, London, Croom Helm
- Bliss J, Ogborn J (1979), *The Analysis of Qualitative Data*, *European Journal of Science Education* 1(4) p427-40
- Blumer H (1969), *Symbolic interactionism: perspective and method*, Englewood Cliffs, NJ, Prentice-Hall
- Bourdieu P (1977), *Outline of a theory of practice*, Cambridge, Cambridge University Press
- BPS (1990), *British Psychological Society Statement of Ethical Principles*, *The Psychologist*, June 1990, p269-272
- Bredo E (1998), *Reconstructing Educational Psychology*, in Murphy P (ed) (1999), *Learners, Learning and Assessment*, London, Sage/PCP, p23-45

- Brickhouse NW (1991), *Teachers' beliefs about the nature of science and their relationship with classroom practice*, Journal of Teacher Education 41(3) 53-62
- Brickhouse NW, Dagher ZR, Letts WJ, Shipman HL (2000), *Diversity of students' views about evidence, theory, and the interface between science and religion in an astronomy course*, Journal of Research in Science Teaching 37(4) p340-362
- Bromme R (1984), *On the limitations of the theory metaphor for the study of teachers' expert knowledge*, in Halkes R, Olson J K (eds) (1984), *Teacher thinking: a new perspective on persisting problems in education*, Lisse, Swets & Zeitlinger 43-57
- Brown L, Angus L (1997), *Reconstructing Teacher Professionalism in Victoria's Schools of the Future*, Curriculum Perspectives 17(1) April 1997 p45-56
- Brown S, McIntyre D (1993), *Making sense of teaching*, Buckingham, Open University Press
- BSA (1993), *British Sociological Association Statement of Ethical Practice*, Durham, British Sociological Association
- Butt RL (1984), *Arguments for using biography in understanding teacher thinking*, in Halkes R, Olson J K (eds) (1984), *Teacher thinking: a new perspective on persisting problems in education*, Lisse, Swets & Zeitlinger 95-102
- Calderhead J & Robson M (1991), *Images of teaching: student teachers' early conceptions of classroom practice*, Teaching and Teacher Education 7(1) p1-8
- Calderhead J (1979), *Teachers' classroom decision-making: its relationship to teachers' perceptions of pupils and to classroom interaction*, Unpublished PhD Thesis, University of Stirling
- Calderhead J (1981), *Stimulated recall: a method for research on teaching*, British Journal of Educational Psychology 51 p211-217
- Calderhead J (1984), *Teachers' classroom decision-making*, London, Holt, Rinehart and Winston
- Calderhead J (1987), *Developing a Framework for the Elicitation and Analysis of Teachers' Verbal Reports*, Oxford Review of Education 13(2) p183-189

- Calderhead J (1988), *The Development of Knowledge Structures in Learning to Teach*, in Calderhead J (ed) (1988), *Teachers' professional learning*, London, Falmer p51-64
- Calderhead J (1991), *The Nature and Growth of Knowledge in Student Teaching*, Teaching and Teacher Education 7(5/6) p531-535
- Calderhead J (1993), *Dilemmas in developing reflective teaching*, Teacher Education Quarterly, Winter 1993 20(1) p93-100
- Calderhead J (1998), *Images of teaching: their relevance for the professional development of student teachers*, Research Seminar, University of Oxford Department of Educational Studies, 19th October 1998
- Calderhead J (ed) (1988), *Teachers' professional learning*, London, Falmer
- Calderhead J, Miller E (1986), *The integration of subject matter knowledge in student teachers' classroom practice*, School of Education, University of Lancaster, Research monograph
- Campbell D T (1960), *Blind variation and selective retention in creative thought as in other knowledge processes*, Psychological Review 67(6) p380-400
- Campbell D T (1974), *Unjustified variation and selective retention in scientific discovery*, in Ayala F J, Dobzhansky T (eds) (1974), *Studies in the Philosophy of Biology*, London, MacMillan, p139-161
- Campbell DT (1979), *Degrees of freedom and the case study*, in Cook TD, Reichardt S (eds), *Quantitative and qualitative methods in evaluation research*, Beverley Hills CA, Sage, p49-66
- Campbell DT and Stanley J (1963), *Experimental and quasi-experimental designs for research on teaching*, in Gage N (ed), *Handbook of Research on Teaching*, Chicago, Rand McNally, p171-246
- Capra F (1996), *The Web of Life*, London, Harper Collins
- Carey S, Evans R, Honda M, Jay E, Ungar C (1990), "An experiment is when you try and see if it works": a study of grade 7 students' understanding of the construction

of scientific knowledge, International Journal of Science Education 11 (Special) 514-529

Caronia L (1999), *Constructing meanings and writing knowledge: on the nature of data in educational field research*, Paper presented at the 18th International Human Sciences Research Conference Sheffield, England, 26-29 July 1999

Carr W (1982), *Treating the symptoms, neglecting the causes: diagnosing the problem of theory and practice*, Journal of Further and Higher Education 6(2) p19-29

Cassels J, Johnstone SH (1985), *Words that matter in science*, Royal Society of Chemistry

Cheung KC, Toh KA (1990), *In the eyes of the beholder: beginning teachers' conception of the nature of science and science teaching*, Paper presented at the 4th Annual Conference of the Educational Research Association, Singapore October 20-21 1990

Clandinin DJ (1986), *Classroom practice: Teacher images in action*, Lewes, Falmer Press

Clarke C (1998), *Resurrecting Educational Research to raise standards: statement from the new minister responsible for research*, Research Intelligence October 1998 p8-9

Claxton G (1990), *Teaching to learn: a direction for education*, London, Cassell

Claxton G (1991), *Educating the enquiring mind: the challenge for school science*, Hemel Hempstead, Harvester Wheatsheaf

Close G, Furlong T, Simon S, (1997), *The Validity of the 1996 Key Stage 2 Tests in English, Mathematics and Science*, A report from King's College London, University of London, commissioned by the Association of Teachers and Lecturers

Collins H, Pinch T (1982), *Frames of meaning*, London, Routledge Kegan Paul

Connelly FM, Clandinin DJ (1984), *Personal practical knowledge at Bay Street School: ritual, personal philosophy and image*, in Halkes and Olson (eds) (1984), *Teacher thinking: a new perspective on persisting problems in education*, Lisse, Swets & Zeitlinger 134-148

- Connelly FM, Clandinin DJ (1985), *Personal practical knowledge and the modes of knowing: relevance for teaching and learning*, in Eisner (ed) (1985), *Learning and teaching the ways of knowing: 84th Yearbook of the Society for the Study of Education*, University of Chicago Press, Chicago p174-198
- Cooper P, McIntyre D (1996), *Effective Teaching and Learning*, Buckingham, Open University Press
- Cronbach LJ (1982), *Designing evaluations of educational and social programs*, San Francisco, CA, Jossey-Bass
- Cross A (1999), *Scientific methods*, *The Teacher*, March 1999
- Cunningham JW, Fitzgerald J (1996), *Epistemology and reading*, *Reading Research Quarterly* 31(1) 36-60
- Davies D (1998), 'Testing the toolkit': strategies to help primary student teachers develop scientific knowledge, *Science Teacher Education*, 22, p8-10
- Day C (1993), *The importance of learning biography in supporting teacher development: an empirical study*, in Day C, Calderhead J, Denicolo P (eds) (1993), *Research on teacher thinking: understanding professional development*, London, Falmer
- de Boo M (1997), *What science did you study at secondary school?*, *Primary Science Review* 47 March 1997
- de Boo M (1989), *The science background of primary teachers*, *School Science Review* 70(252) 125-7
- de Groot AD (1965), *Thought and choice in Chess*, The Hague, Mouton Press
- Dearden RF (1968), *The Philosophy of Primary Education*, London, Routledge and Kegan Paul
- Denzin NK (1983), *Interpretive Interactionism*, in Morgan G (ed) (1983), *Beyond Method: Strategies for Social Research*, Sage, Beverly Hills, CA, p129-146
- DES (1978), *Primary Education in England (HMI)*, London, HMSO

- DES (1985), *Science 5-16: A statement of policy*, London, HMSO
- DES (1988), *The Language of Science*, London, APU, DES
- DES (1989), *Aspects of primary education: the teaching and learning of science*, London, HMSO
- DES (1994), *The National Curriculum Orders*, London, HMSO
- DfE (1995), *The National Curriculum*, London, HMSO
- DfEE (1996a), *Results of the 1995 National Curriculum Assessments of 11 year olds in England*, London, Department for Education and Employment
- DfEE (1996b), *Results of the 1996 National Curriculum Assessments of 11 year olds in England*, London, Department for Education and Employment
- DfEE (1997a), *Results of the 1997 National Curriculum Assessments of 11 year olds in England: a summary for heads and governors*, London, Department for Education and Employment
- DfEE (1997b), *Circular 10/97 Requirements for courses for Initial Teacher Training*, London, Department for Education and Employment
- DfEE (1998a), *Excellence in Research on Schools*, London, HMSO
- DfEE (1998b), *Circular 4/98 Requirements for courses for Initial Teacher Training*, London, Department for Education and Employment
- DfEE (1999), *Statistics of Education, Teachers, England and Wales*, London, Department for Education and Employment
- Dillon C (1994), *Qualitative reasoning about physical systems - an overview*, *Studies in Science Education* 23 39-57
- Doyle & Ponder (1977), *The Practicality Ethic in Teacher Decision-Making*, Interchange. 8(3) p1-12
- Driver R, Leach J, Millar R, Scott P (1996), *Young people's images of science*, Buckingham, Open University Press

- Driver R, Asoko H, Leach J, Mortimer E, Scott P (1994), *Constructing scientific knowledge in the classroom*, Educational Researcher May 1994
- Driver R (1983), *The pupil as scientist?*, Milton Keynes, Open University Press
- Durant J, Evans G, Thomas G (1989), *The Public Understanding of Science*, Nature 340 11-14
- Ebenezer JV, Hay A (1995), *Pre-service teachers' meaning-making in science instruction: a case study in Manitoba*, International Journal of Science Education 17(1) 1995
- Eisner E (1984), *No Easy Answers: Joseph Schwab's Contribution to Curriculum*, Curriculum Inquiry 14(2) p201-210
- Elbaz F (1983), *Teacher thinking: a study of practical knowledge*, London, Croom Helm
- Elliott J (1990), *Validating Case Studies*, Westminster Studies in Education, Vol. 13, 1990
- Entwhistle H (1970), *Child-centred education*, London, Methuen
- Eraut M (1988), *Management knowledge: its nature and its development*, in Calderhead J (ed) (1988), *Teachers' professional learning*, London, Falmer p196-204
- Ericsson KA, Simon HA (1993), *Protocol analysis: verbal reports as data*, Cambridge, Mass., MIT Press
- ESRC (1999), *ESRC Teaching and Learning Research Programme: Specification for Phase II*, Economic and Social Research Council
- Feyerabend PK (1975), *Against method*, London, New Left Books
- Feyerabend PK (1981), *Philosophical Papers*, Cambridge, Cambridge University Press
- Firestone WA, Herriott RE (1984), *Multi-site qualitative policy research: some design and implementation issues*, in Fetterman DM (ed) (1984) *Ethnography in Educational Evaluation*, Beverley Hills, CA, Sage, p63-88

- Foddy W (1993), *Constructing questions for interviews and questionnaires*, Cambridge, Cambridge University Press
- Foster P (1999), *Some critical comments on the BERA Ethical Guidelines*, Research Intelligence, BERA Newsletter No. 67, Feb 1999, p24-27
- Galton M, Simon B, Croll P (1980), *Inside Primary Classrooms*, London, Routledge and Kegan Paul
- Gardner H (1986), *The mind's new science: a history of cognitive revolution*, New York, Basic Books
- Geertz C (1973), *Thick description: toward an interpretive theory of culture*, in Geertz (ed) (1973), *The Interpretation of Cultures*, New York, Basic Books p3-30
- Geertz C (1993), *Local knowledge and its limits: some obiter dicta*, The Yale Journal of Criticism 5 p129-135
- Gell-Mann M (1994), *The Quark and the Jaguar*, London, Abacus
- Giddens A (1990), *The Consequences of Modernity*, Cambridge, Polity Press
- Giddens A (1991), *Modernity and Self-Identity: Self and Society in the Late Modern Age*, Cambridge, Polity Press
- Goetz JP, LeCompte MD (1984), *Ethnography and qualitative design in education research*, Orlando, FL, Academic Press
- Goodson IF (1991), *Teachers' lives and educational research*, in Goodson & Walker (eds) (1991), *Biography, identity, and schooling: episodes in educational research*, London, Falmer
- Goodson IF, Hargreaves A (eds) (1996), *Teachers' Professional Lives*, London, Falmer
- Goodson IF, Ball SJ (1984) (eds), *Defining the curriculum: histories and ethnographies*, London, Falmer
- Goodson IF (ed) (1992a), *Studying teachers' lives*, New York, Teachers College Press

- Goodson IF (1992b), *Studying teachers' lives: problems and possibilities*, in Goodson (1992a), *Studying teachers' lives*, New York, Teachers College Press p234-249
- Goodson IF (1992c), *Studying teachers' lives: an emergent field of inquiry*, in Goodson (1992a), *Studying teachers' lives*, New York, Teachers College Press p1-17
- Goodson IF (1983), *Teachers' lives in educational research*, in Hammersley, M. (ed) *The ethnography of schooling*, Nafferton Driffield, Yorks.
- Gordon D (1984), *The Image of Science, Technological Consciousness, and the Hidden Curriculum*, *Curriculum Inquiry* 14(4)
- Guba EG, Lincoln YS (1981), *Effective evaluation: improving the usefulness of evaluation results through responsive and naturalistic approaches*, San Francisco, Jossey-Bass
- Guba EG, Lincoln YS (1982), *Epistemological and methodological bases of naturalistic enquiry*, *Educational Communication and Technology Journal* 30 p233-252
- Gunnell B (1999), *Meeting the children*, *Education in Science* 181, Feb 1999, p10-11
- Gustafson BJ, Rowell PM (1995), *Elementary pre-service teachers: constructing conceptions about learning science, teaching science and the nature of science*, *International Journal of Science Education* 17(5) 1995
- Hacking I (1983), *Representing and Intervening*, Cambridge, Cambridge University Press
- Hair JF, Anderson RE, Tatham RL, Black WC (1995), *Multivariate Data Analysis*, Englewood Cliffs, NJ, Prentice Hall
- Halkes R, Olson J K (eds) (1984), *Teacher thinking: a new perspective on persisting problems in education*, Lisse, Swets & Zeitlinger
- Hammersley M (1991), *Reading Ethnographic Research: A Critical Guide*, London, Longman
- Hammersley M (1995), *The Politics of Social Research*, London, Sage

- Hammersley M (ed) (1993), *Educational Research: Current Issues*, London, Open University/PCP
- Hammersley M, Atkinson P (1995), *Ethnography: principles in practice (2nd ed)*, London, Routledge
- Hand B, Treagust DF, Vance K (1997), *Student perceptions of the Social Constructivist Classroom*, *Science Education* 81(5) p561-576
- Hansen K-H, Olson J (1996), *How teachers construe curriculum integration: the Science, Technology, Society (STS) movement as Bildung*, *Journal of Curriculum Studies* 28(6) p669-682
- Harding P, Hare W (2000), *Portraying Science Accurately in Classrooms: Emphasizing Open-Mindedness Rather Than Relativism*, *Journal of Research in Science Teaching* 37(3) p225-236
- Hargreaves A, Goodson I (1996), *Teachers' Professional Lives: Aspirations and Actualities*, in Goodson and Hargreaves (eds) (1996), p1-27
- Harland J, Kinder K (1997), *Teachers' continuing professional development: framing a model of outcomes*, *British Journal of In-service Education* 23(1) p71-84
- Harlen W (1997), *Ten years on - the past and the future of research in primary science*, *Primary Science Review* 47 March 1997
- Harlen W, Holroyd C (1997), *Primary teachers' understanding of concepts of science: impact on confidence and teaching*, *International Journal of Science Education* 19(1) p93-105
- Harré R (1979), *Social Being*, Oxford, Blackwell
- Harré R (1983), *Personal Being*, Oxford, Blackwell
- Harré R (1986), *Varieties of realism*, London, Blackwell
- Harré R (1991), *Physical Being*, Oxford, Blackwell
- Harré R (1998), *The singular self: an introduction to the psychology of personhood*, London, Sage

- Harré R, van Langenhove L (1999), *The dynamics of social episodes*, in Harré and van Langenhove (eds) (1999), *Positioning Theory*, Oxford, Blackwell p1-13
- Harré R, van Langenhove L (eds) (1999), *Positioning Theory*, Oxford, Blackwell
- Harris S, Keys W, Fernandes C (1997), *Third International Mathematics and Science Study: Second National Report: Part 1*, Slough, NFER
- Hart P (1996), *Problematizing Enquiry in Environmental Education: Issues of Method in a Study of Teacher Thinking and Practice*, Canadian Journal of Environmental Education, 1, p56-88
- Helms JV (1998), *Science - and Me: Subject Matter and Identity in Secondary Science Teachers*, Journal of Research in Science Teaching 35(7) p811-834
- Hodson D (1988), *Toward a philosophically more valid science curriculum*, Science Education 72(1) p19-40
- Hodson D (1993), *Philosophic stance of secondary school science teachers, curriculum experiences, and children's understanding of science: some preliminary findings*, Interchange 24(1&2) p41-52
- Holroyd C, Harlen W (1995), *Developing understanding of science: the challenge for primary teacher education in Scotland*,
- Holt-Reynolds D (1992)), *Personal history-based beliefs as relevant prior knowledge in course work*, American Educational Research Journal 29(2) p325-349
- Howe AC (1996), *Development of science concepts within a Vygotskian framework*, Science Education 80(1) p35-51
- Hoyle E, Megarry J (eds) (1980), *World Yearbook of Education*, London, Kogan Page
- Joyce B, Showers B (1984), *Transfer of training: the contribution of 'coaching'*, in Hopkins D and Wideen M (eds) (1984), *Alternative perspectives on school improvement* Sussex, Falmer Press
- Keddie N (1971), *Classroom knowledge*, in Young (ed) (1971), *Knowledge and control*, Collier-MacMillan, London p133-160

- Kennedy MM (1998), *Education Reform and Subject Matter Knowledge*, Journal of Research in Science Teaching 35(3) p249-263
- King, Ronald (1984), *The man in the Wendy house: researching infants' schools*, in Burgess RG, *The Research Process in Educational Settings*, Lewes, Falmer
- King, Ronald (1989), *The best of primary education?: a sociological study of junior middle schools*, Lewes, Falmer
- Kitcher P (1993), *The advancement of science: science without legend, objectivity without illusions*, Oxford, Oxford University Press
- Kline P (1994), *An easy guide to Factor Analysis*,
- Koulaidis V (1987), *Philosophy of science in relation to curricular and pedagogical issues: a study of science teachers' opinions and their implications*, Unpublished PhD thesis, University of London
- Koulaidis V, Ogborn J (1988), *Use of systemic networks in the development of a questionnaire*, International Journal of Science Education 10(5) 497-509
- Koulaidis V, Ogborn J (1989), *Philosophy of science: an empirical study of teachers' views*, International Journal of Science Education 11(2) 173-184
- Koulaidis V, Ogborn J (1995), *Science teachers' philosophical assumptions: how well do we understand them?*, International Journal of Science Education 17(3) 1995
- Krathwohl DR (1985), *Social and Behavioural Science Research: a new framework for conceptualizing, implementing and evaluating research studies*, San Francisco, Jossey-Bass
- Kruger C, Palacio D, Summers M (1990), *An investigation of some primary school teachers' understanding of the concepts of force and gravity*, British Educational Research Journal 16(4) p383-97
- Kuhn TS (1970), *The structure of scientific revolutions (2nd edn)*, Chicago, University of Chicago Press

- Lacey C (1970), *Hightown Grammar: the school as a social system*, Manchester, Manchester University Press
- Lacey C (1977), *The socialization of teachers*, London, Methuen
- Lakatos I (1970), *Falsification and the methodology of scientific research programmes*, Cambridge, in Lakatos I & Musgrave A (eds), *Criticism and the growth of knowledge*, Cambridge University Press
- Lakin S, Wellington J (1994), *Who will teach the 'nature of science'? : teachers' views of science and their implications for science education*, International Journal of Science Education 16(1)
- Lambert H, Rose H (1990), *Disembodied knowledge? Making sense of medical knowledge*, London Science Museum, Paper given at the Conference on Policies for Public Understanding of Knowledge
- Larochelle M, Desautels J (1991), *"Of course it's just obvious": adolescents' ideas of scientific knowledge*, International Journal of Science Education 13(4) 373-389
- Latour B, Woolgar S (1986), *Laboratory Life: the construction of scientific facts (2nd edition)*, Princeton, NJ, Princeton University Press
- Laudan L (1984), *Science and values*, Berkeley, CA, University of California Press
- Lave J, Wenger E (1991), *Situated Learning: Legitimate Peripheral Participation*, Cambridge, Cambridge University Press
- LeCompte MD, Goetz JP (1982), *Problems of reliability and validity in ethnographic research*, Review of Educational Research 52(1), Spring 1982
- Lederman NG (1999), *Teachers' understanding of the nature of science and classroom practice: factors that facilitate or impede the relationship*, Journal of Research in Science Teaching 36(8) 916-929
- Lederman N, Zeidler D (1987), *Science teachers' conceptions of the nature of science: do they really influence teaching behaviour?*, Science Education 71(5) 721-734
- Lehmann F (1992), *Semantic Networks*, Journal of Computers and Mathematics with Applications, 23(2-5) p1-50

- Lincoln YS, Guba E (1985), *Naturalistic Inquiry*, Beverly Hills, CA, Sage
- Lunn S, Solomon J (forthcoming), *Primary teachers' thinking about the English National Curriculum for science: auto-biographies, warrants, and autonomy.*, Journal of Research in Science Teaching, December 2000 issue
- Lunn S (1996), *Primary Teachers' perceptions of the nature of science and the purposes of science education: a preliminary investigation*, University of Oxford MSc Dissertation
- Macaskill C, Ogborn J (1996), *Science and technology*, School Science Review June 1996 77(281) p55-61
- Mant J, Summers M (1993), *Some primary-school teachers' understanding of the Earth's place in the universe*, Research Papers in Education 8(1) March 1993
- McIntyre D (1995), *Ten characteristics of a good research question*, personal communication, October 1995
- Measor L (1985), *Interviewing: a strategy in qualitative research*, in Burgess RG (ed) (1985) *Strategies in Educational Research: Qualitative Methods*, Lewes, Falmer
- Measor L, Sikes P (1992), *Visiting Lives: ethics and methodology in Life History*, in Goodson 1992 (ed), *Studying teachers' lives*, New York, Teachers College Press p209-233
- Mellado V (1997), *Pre-service teachers' classroom practice and their conceptions of the nature of science*, Science & Education 6(4) p331-354
- Merton RK (1975), *Structural analysis in sociology*, in Blau P (ed) (1975), *Approaches to the study of social structure*, The Free Press, New York
- Michael M (1992), *Lay discourses of science: science-in-general science-in-particular and self*, Science, Technology, and Human Values 17(3)
- Millar R (1996), *Towards a science curriculum for public understanding of science*, School Science Review 77(280) p7-18

- Millar R, Driver R (1987), *Beyond processes*, Studies in Science Education 14 (1987) p33-62
- Miller J, Prewitt K, Pearson R (1980), *The attitudes of the US public towards science and technology*, Report to the NSF, Public Opinion Laboratory
- Milner B (1986), *Why teach science and why to all?*, in Nellist J, Nicholl B (eds), The ASE Science Teacher's Handbook, London, Hutchinson, p1-10
- Mokyr J (2000), *Evolutionary phenomena in technological change*, in Ziman (ed) (2000), *Technological Innovation as an Evolutionary Process*, Cambridge, Cambridge University Press
- Monk M (1995), *On the identification of principles in science that might inform research into students' beliefs about natural phenomena*, International Journal of Science Education 17(5)
- Morgan G (ed) (1983), *Beyond Method: Strategies for Social Research*, Beverly Hills, CA, Sage
- Murcia K, Schibeci R (1999), *Primary student teachers' conceptions of the nature of science*, International Journal of Science Education 21(11) p1123-1140
- Murphy P (1997), *Constructivism and primary science*, Primary Science Review 49
- Noblit GW, Hare RD (1988), *Meta-Ethnography: synthesizing qualitative studies*, Beverley Hills, CA, Sage
- Nott M, Wellington J (1993), *Your nature of science profile: an activity for science teachers*, School Science Review 75 (270) p109-112
- Nott M, Wellington J (1998), *Eliciting, interpreting and developing teachers' understanding of the nature of science*, Science Education 7 p579-594
- Oakley A (1981), *Interviewing women: a contradiction in terms*, in Roberts H (ed) (1981), *Doing Feminist Research*, London, Routledge and Kegan Paul
- Open University (1998), *U500 Doing Academic Research*, Milton Keynes, The Open University

- Orpwood G, Barnett J (1997), *Science in the National Curriculum: an international perspective*, The Curriculum Journal 8(3) p331-349
- Osborne JF (1996), *Beyond constructivism*, Science Education 80(1) p53-82
- Osborne JF, Black P, Smith M, Meadows J (1990), *SPACE Research Report: Light*, Liverpool University Press, Primary SPACE Project Research Report January 1990
- Osborne JF, Simon S (1996), *Primary Science: Past and Future Directions*, Studies in Science Education 26 p99-147
- Peterson PL, Clark CM (1978), *Teachers' reports of their cognitive processes during teaching*, American Educational Research Journal 15 p555-565
- Polanyi M (1958), *Personal Knowledge: towards a post-critical philosophy*, London, Routledge Keegan Paul
- Pollard A (1985), *Opportunities and difficulties of a teacher-ethnographer: a personal account*, in Burgess RD (ed) (1985), *Field methods in the study of education*, Lewes, Falmer
- Pomeroy D (1993), *Implications of teachers' beliefs about the nature of science: comparison of the beliefs of scientists secondary science teachers and elementary teachers*, Science Education 77(3) 261-278
- Popper K (1968), *Conjectures and refutations: the growth of scientific knowledge*, London, Routledge Kegan Paul
- Popper K (1970), *Normal Science and its dangers*, in Lakatos I, Musgrave A (eds) (1970), *Criticism and the growth of knowledge*, Cambridge, Cambridge University Press
- Popper K (1972), *Objective Knowledge: an evolutionary approach*, Oxford, Clarendon Press
- QCA (1998), *Standards at Key Stage 2, English, Mathematics and Science: Report on the 1998 Curriculum Assessments for 11-year-olds. A report for headteachers, class*

teachers and assessment co-ordinators, London, Qualifications and Curriculum Authority

Rubba P (1976), *Nature of Scientific Knowledge Scale*, Unpublished manuscript, Indiana University; quoted in Lederman and Zeidler 1987

Ruddock J (1988), *The ownership of change as a basis for teachers' professional learning*, in Calderhead J (ed) (1988), *Teachers' professional learning*, London, Falmer p205-22

Russell T (1988), *From Pre-service Teacher Education to First Year of Teaching: A Study of Theory and Practice*, in Calderhead J (1988), *Teachers' professional learning*, London, Falmer p13-34

Schofield JW (1989), *Increasing the generalisability of qualitative research*, in Eisner and Peshkin (eds) (1989), *Qualitative Inquiry in Education: the Continuing Debate*, Teachers College Press, New York, p201-232

Schön DA (1983,1991), *The Reflective Practitioner: how professionals think in action*, Aldershot Hants, Avebury

Schutz A, Luckmann T (1973), *The Structures of the Life-World* (translated by Zaner R, Engelhardt T), Evanston, Illinois, North-western University Press

Schwab JJ (1964), *The structure of the disciplines: Meanings and significances*, in Ford GW, Pugno L (eds) (1964), *The structure of knowledge and the curriculum*, Chicago, Rand McNally

Shank RC, Abelson RP (1977), *Scripts, Plans, Goals and Understanding: an inquiry into human knowledge structures*, New Jersey, Erlbaum

Shulman LS (1981), *A View from Educational Psychology*, Educational Theory 31(1) p37-42

Shulman LS (1984), *The Practical and the Eclectic: A Deliberation on Teaching and Educational Research*, Curriculum Inquiry 14(2) p183-200

- Shulman LS (1986), *Those who Understand: Knowledge Growth in Teaching*, Educational Researcher 15(2) Feb 1986 p4-14
- Shulman LS (1987), *Knowledge and Teaching: Foundations of the New Reform*, Harvard Educational Review 57(1) Feb 1987 p1-22
- Shulman LS, Keislar ER (eds) (1966), *Learning by Discovery: a critical appraisal*, Chicago, Rand McNally
- Simmons PE, Emory A, Carter T, Coker T, Finnegan B, Crockett D, Richardson L, Yager R, Craven J, Tillotson J, Brunkhorst H, Twiest M, Hossain K, Gallagher J, Duggan-Haas D, Parker J, Cajas F, Alshannag Q, McGlamery S, Krockover J, Adams P, Spector B, LaPorta T, James B, Rearden K, Labuda K (1999), *Beginning teachers: beliefs and classroom actions*, Journal of Research in Science Teaching 36(8) p930-954
- Smith DC, Neale DC (1989), *The construction of subject matter knowledge in primary science teaching*, Teaching and teacher education 5 p1-20
- Solomon J (1980), *Teaching children in the laboratory*, London, Croom Helm
- Solomon J (1983), 'Is Physics Easy?', Physics Education 18 p155-159
- Solomon J (1985), *Learning and Evaluation: A Study of School Children's Views on the Social Uses of Energy*, London, Sage
- Solomon J (1987), *Signs of change in the science class*, New Scientist, 5th Feb 1987, p73-74
- Solomon J (1989), *Discussing Nuclear Power*, Physics Education 24 p344-347.
- Solomon J (1993), *Teaching science technology and society*, Buckingham, Open University Press
- Solomon J (1994), *The rise and fall of constructivism*, Studies in Science Education 23 1-19
- Solomon J (1995), *Higher level understanding of the nature of science*, School Science Review 76 276 15-22

- Solomon J (1997a), *Scientific knowledge and its publics: part 1*, OU Research Paper
- Solomon J (1997b), *Scientific knowledge and its publics (part 2): in school and outside*, OU Research Paper
- Solomon J (1997c), *Girls' science education: choice, solidarity and culture*, International Journal of Science Education 19(4) p407-417
- Solomon J, Scott L, Duveen J (1996), *Large-scale exploration of pupils' understanding of the nature of science*, Science Education 80(5) p493-508
- Solomon J, Tresman S (1999), *A model for continuing professional development: knowledge, belief and action*, Journal of In-service Education 25(2) p307-319
- Solomon J, Duveen J, Scott L (1994), *Pupils' images of scientific epistemology*, International Journal of Science Education 16(3) p361-373
- Solomon J, Palacio D (1988), *Teachers talking: memories of personal failure have helped shape primary science*, Times Educational Supplement 21.10.88
- Storr A (1979), *The art of psychotherapy*, London, Secker & Warburg
- Strauss AL, Corbin J (1990), *Basics of Qualitative Research*, London, Sage
- Sugrue C (1996), *Student teachers' lay theories: implications for professional development*, in Goodson and Hargreaves (eds) (1996), *Teachers' Professional Lives*, London, Falmer p154-177
- Summers M (1994), *Science in the primary school: the problem of teachers' curricular expertise*, The Curriculum Journal 5(2)
- Taylor C (1985), *Human agency and language*, Cambridge, Cambridge University Press
- Toumey CP (1996), *Conjuring science: scientific symbols and cultural meanings in American life*, New Brunswick, New Jersey, Rutgers University Press
- Tymms P, Gallacher S (1995), *Primary Science: an exploration of differential classroom success*, Research in Science & Technological Education, 13(2)

- Ulichny P, Schoener W (1996), *Teacher-Researcher Collaboration from Two Perspectives*, Harvard Education Review 66(3) p496-524
- Waugh R, Godfrey J (1993) , Teacher receptivity to System-wide Change in the Implementation Stage, *British Educational Research Journal*, 19(5), p565-578.
- Wilson S (1979), *Explorations of the usefulness of case study evaluations*, Evaluation Quarterly 3
- Wolfe LF (1983) , *Toward understanding the ideas about science communicated by elementary school teachers* , Jn'83. ix, [394] University of Toronto, O.I.S.E.
- Woods P (1984), *Teacher, self and curriculum*, in Goodson and Ball 1984 (eds), *Defining the curriculum: histories and ethnographies*, London, Falmer p1-26
- Woods P (1993), *Managing marginality: teacher development through grounded life history*, British Educational Research Journal 19(5) p447-66
- Woolnough B (1994), *Effective science teaching*, Milton Keynes, Open University Press
- Wragg EC, Bennett SN, Carre CG (1989), *Primary Teachers and the National Curriculum*, Research Papers in Education 4(3) p17-45
- Yin RK, Heald KA (1975), *Using the case survey method to analyze policy studies*, Administrative Science Quarterly 20 p371-381
- Ziman J (1984), *An introduction to science studies: the philosophical and social aspects of science and technology*, Cambridge, Cambridge University Press
- Ziman J (2000), *Real Science*, Cambridge, Cambridge University Press

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1. Glossary of terms and abbreviations

APU	Assessment of Performance Unit
ASE	Association for Science Education
AT1	the National Curriculum's attainment target one - shorthand for 'Experimental and investigative science' or 'Scientific enquiry', also known as Sc1 or Science 1
BA	Bachelor of Arts
BEd	Bachelor of Education degree
BERA	British Educational Research Association
BPS	British Psychological Association
BSA	British Sociological Association
Cert.Ed.	Certificate of Education
D&T	Design and Technology
DES	Department of Education and Science
DfE	Department for Education
DfEE	Department for Education and Employment
Dipsy	Discursive Psychology Discussion Group at the OU
ESERA	European Science Education Research Association
ESRC	Economic and Social Research Council
GCE O Level	General Certificate of Education - Ordinary Level: superseded by GCSE
GCE A Level	General Certificate of Education - Advanced Level
GCSE	General Certificate of Secondary Education
GM	Grant Maintained School
GM Foods	Genetically Modified Foods
GMO	Genetically Modified Organism
HMI	Her Majesty's Inspectors of Schools
HMSO	Her Majesty's Stationery Office
HNC	Higher National Certificate
ICT	Information and Communication Technology
INSET	In-Service Training
ITE	Initial Teacher Education
KS1	Key Stage 1, Y1-Y2: a new name for 'Infants', or the first two year of school, introduced with the NC

KS2	Key Stage 2, Y3-Y6: a new name for 'Juniors', or 7- to 11-year-olds, introduced with the NC
KS3	Key Stage 3, Y7-Y9: a new name for 'Lower Secondary', or 11- to 14-year-olds, introduced with the NC
LEA	Local Education Authority
MS Excel	Spreadsheet software for PCs
NC	National Curriculum
NFER	National Foundation for Educational Research
NOS	Nature of Science
OFSTED	Office for Standards in Education
ONC	Ordinary National Certificate
OQSA	Oxfordshire Quality Schools Association
OU	Open University
OU course E833	Module of the OU's MA in Education in 1998/99: "Primary education: assessing and planning learning"
PE	Physical Education
PGCE	Post-Graduate Certificate in Education
Quadrat	In ecology, an area, usually of 1 sq. m., selected at random for study of plants
QCA	Qualifications and Curriculum Authority
R/Y1	Reception/Year 1
SATs	Standardised Attainment Tests
Sc1 or Science 1	'Experimental and investigative science' or 'Scientific enquiry', as defined by the National Curriculum
SPACE	Nuffield-funded, classroom-based primary science research project
SPSS	Statistics software for PCs
STS	Science, Technology and Society
Y1, Y2, etc.	Year 1, the first full academic year, etc.

2. Briefing note for participants

The briefing note given to teachers participating in the project, or thinking of doing so, described the project as follows:

Purpose and general approach

The project will look at the nature and development of primary teachers' professional self-image, of their conception of science teaching, of their confidence in teaching science, and of the knowledge they bring to bear in teaching science; and how these are influenced by reflection on the nature of the subject matter.

The work forms part of a more widespread move to understand the distinctive nature of the professional development of teachers; how professional knowledge is developed and used in practice; and the relationships between professional self-image, images of science and science teaching, and generic and subject-specific knowledge.

The general approach is non-judgemental: I am not comparing what teachers do or say to some theoretical or ideological 'right answer', but simply trying to document how different people approach things, and to learn something by identifying common ground and contrasts.

Reports of the project will be published in due course. I guarantee confidentiality and anonymity to participants, in particular to keep the names of participating teachers and their schools confidential, and to make sure that any quotes from interview transcripts and observation notes are anonymous.

Schedule of sessions

All participants teach science (amongst other subjects) to pupils in years 1 to 6. There are normally one or two participants from any one school.

Participation involves taking part in five tape-recorded discussions, each lasting 30 to 60 minutes, in the period up to summer term 1999, i.e. around one to two hours per term for three to five terms. The discussions will be about the planning associated with teaching a science topic, and about primary science teaching in general. Provided it can be done without disruption or inconvenience, I will also observe one or two science lessons early on and towards the end of the project.

In the first and fifth sessions the focus is on the preparation and planning of a topic or unit. In between these are three 'interview sessions', where the teacher is encouraged to reflect on their own science education, the nature of science, and the purposes of teaching it in primary schools, etc. Teachers should feel free to raise any queries or issues that have occurred to them in any of the sessions, though full discussion of these may be deferred to the final session.

Interview sessions normally take place at the end of the school day, in the teacher's classroom.

When these sessions have been completed, I am very willing to come back to discuss any queries or comments that have cropped up, and to give commentary and feedback on what has been said and seen, if the teacher wishes.

How to get the most out of taking part

The experiences of teachers taking part in the pilot work for this project (in 1996) were generally positive. None felt that taking part had been a waste of time; most felt they gained by the experience, as a result of being stimulated to reflect on their practice and on science in ways that they had not done before; and some felt that their involvement was a definite spur to professional development.

This phase of the project is more spread out in time and gives more opportunities for reflection: what teachers get out of the project will depend on their reflections on what we have been talking about, on science, science teaching, teaching in general, etc., stimulated by or arising in parallel to the interview sessions. It may help to jot down a few notes about such reflections, to help recall and raise them in discussions later on: to this end, a 'Notes, queries and comments' sheet is included in the participant's pack, and anything that occurs to you that you think might be relevant to our discussions should be noted there.

3. Dates and Durations of Interviews and Observations

	Int.1 Planning	Obs.1	Int.2 Life history	Int.3 Nature of science	Int.4 Primary science	Int.5 Planning revisited	Obs.2
Andrew	Feb'98 1hr05	Jun'98 0hr50	Nov'98 1hr00	Feb'99 1hr20	Mar'99 1hr50	Jun'99 2hr35	Jul'99 1hr15
Howard	Mar'98 1hr00	Apr'98 2hr30	Nov'98 0hr45	Feb'99 1hr00	Mar'99 1hr00	Apr'99 0hr55	Apr'99 1hr40
Irene	Mar'98 1hr00	Nov'98 0hr55	Jan'99 0hr50	Feb'99 0hr40	Mar'99 0hr40	Jun'99 0hr50	Jun'99 1hr00
Keith	Mar'98 0hr45	Nov'98 0hr55	Jan'99 0hr45	Feb'99 0hr50	Mar'99 0hr45	Jun'99 1hr00	Jun'99 0hr55
Linda	Jun'98 1hr30	Jun'98 2hr00	Nov'98 1hr00	Feb'99 1hr05	Apr'99 0hr55	May'99 2hr00	Jun'99 1hr40

4. Interview Schedules

4.1 Interview 1: Planning 1

This was treated as a checklist: the interviewee was invited to talk about what they were doing as they planned a unit: the checklist provided prompts and reminders for the interviewer.

Class:

- description
- how many children
- age groups
- ability groups
- predicted problems

Unit as a whole:

- unit/topic being planned
- Nat Curric bits being addressed
 - main components
 - models
 - explanations
 - learning objectives
- will they do this topic again before SATS?
- done it before?
 - how many times?
 - how recently?
- how does this plan differ from last time?
- introducing the subject
- children's preconceptions
- capturing attention - how do you start?
- relevance of making children aware of problems with their everyday understanding
- differentiation:
 - less able
 - more able

Lessons:

- how many lessons
- structure/mix of activities e.g. between content, demonstration, investigation

Each Lesson (elaborate):

- sequence of activities
- how do you start?
- how long do the bits take?
- which bits do they find easy? .. hard?
- examples of
 - worksheets
 - practical activities

Catch-all questions:

- Why do you do it that way?
- How long does that take?
- Does it always go to plan?
- Which bits do they find easy? ... hard?

Is this part of the science curriculum that:
you think is especially important/valuable?
should be given more/less emphasis?
provides special insights into the nature of science?

4.2 Interview 2: Biography

can you remember doing any science at primary school yourself?

if so what kind of thing?

at secondary school, did you have to make a choice of subjects at 14 (say)?

what choices did you make?

how did you get on?

how did you feel about sciences at the time?

what about A levels?

how did you train?

any specialisms during your diploma/BEd/PGCE?

if science specialism or science degree before PGCE - did you ever cover anything on the nature of science or philosophy of science?

have you done anything other than teaching either before or after qualifying?

since qualifying, have you had any inset to do with science?

if so what was its main focus?

were there any key figures or memorable episodes to do with science? either inspiring or putting you off it?

have you any personal contacts with anyone involved in science, for instance as a working scientist?

if so what sort of thing are they involved in?

would you now say you're a person who is interested in science?

4.3 Interview 3: Nature of Science

this is about the nature of science itself, not about science education: there are a number of straightforward-ish questions, and a couple of 'experimental' questions at the end if we have time ...

what would you say that science actually is?

what does it do for us?

- a way of finding out about the reality that lies behind the world of appearances.
- science is only about observables, and tells us nothing about any underlying reality.

- the world of appearances is reality: science gives us an ordered account of it.
- what matters is whether it is useful to us in understanding our experience of the world.

physics, chemistry, biology are obviously scientific disciplines - what other disciplines would you include in science? what about maths? geography? economics? sociology? psychology? medicine? ...

which curriculum subjects are most similar to science?

which are most different?

someone says something is 'scientifically proven': who might it be speaking? and what are they trying to tell you about it?

how would you tell whether something was scientific or not?

is scientific knowledge different from other?

are all forms of knowledge equally valid?

here's a list of the kinds of things that scientists talk about - are they real (in the sense that chairs, tides, trees are real - or a different sense)?

if they're not real, what are they? ... just elements in theories? does it matter?

what does the term 'scientific method' mean to you?

does a scientist conducting an experiment think s/he knows what is going to happen?

what is a scientific theory? where do theories come from? what are theories for?

facts, ideas, theories, knowledge - what's the distinction?

does scientific knowledge progress? .. how?

what qualities make a good scientist?

what do you think motivates scientists?

why does/should science matter to non-scientists?

what is the relationship between science and morality?

that's the last of the real questions - there's a couple of experimental ones that I'd like to try if you've got time ...

a few questions about head lice: is it true that, why do you think that, is there any evidence that ...

they prefer clean hair?

they prefer long hair to short?

they prefer girls to boys? are discouraged by testosterone?

they are discouraged by conditioner?

the best way to get rid of them is by using insecticidal treatments from the chemists?

or by using a herbal/essential oils mixture, like tea tree oil and lavender?

or by using an infusion of quassia chips?

or by regular conditioning and combing?

I'll just have a quick look at the q'aire you did, see if any points come up ...

Post-amble: thanks for your time. I will send a transcript as soon as I can. if you see anything you disagree with, please let me know, or if there is anything you want to add.

4.4 Interview 4: Primary Science Education

last time we talked about the nature of science itself: this time the focus is on science education in primary school...

Images of teaching/sci teaching:

imagine a classroom.. someone's teaching in it (not you) ... what comes to your mind, what pictures, words, ideas, feelings, when you think of '**teaching**'? what's going on in the picture? is it a classroom? what's happening?

what comes to your mind when you think of '**science teaching**'?

still in this classroom .. but now you're teaching, it's a good lesson .. what comes to your mind when you think of '**good science teaching**'? what makes it good?
what comes to your mind when you think of '**good teaching**'?

teacher as mountain guide; shepherd; manager; wizard; gardener; sheepdog; drill sergeant; courier; conductor

how do you see the science teacher's job?

how about the pupils' job? do you have any theories about how children learn in general? learn science? are there specific things about learning science that would be less important in other subjects?

can you think of any really great moments in your teaching career? when things really went well or ..? your greatest success?

how about the worst moments? what's the most embarrassing thing that ever happened? your worst failure?

Approaches to primary science:

do you ever discuss science stories from the news/media with your class?

if not, why not?

if yes, most recent issue discussed

if you had a term's sabbatical to do something to improve your science teaching, what would you like to work on?

"If you don't know it, you can't teach it": do you agree? why? how can you know everything in depth? does that mean there should be specialist subject teachers in primary schools?

sooner or later someone is bound to ask a question that you don't know the answer to .. how do you deal with it?

How important do you think it is to set science into meaningful contexts? Could you give some examples of how you might do that?

How important do you think it is to make connections between science and other subjects? Children's home or other out-of-school experiences? Could you give some examples of how you might do that?

Changes to primary science:

if you had a free hand ...

if there was no curriculum, you could teach just what you wanted - what would it be?

if you could wave a magic wand and change any two things, what would they be?

Concerns when teaching science:

what are your main concerns?

[e.g. Being able to explain the concepts at the children's level.

Whether your planned activity is really science.

Lack of or inappropriate resources.

That you do not know enough of the relevant science.

That you do not know whether you know enough of the relevant science.

How to make a boring topic interesting to the children.

How to organise and manage behaviour in practical work.

Knowing when to intervene when someone seems to be struggling.]

Purposes of primary science:

what are do you think the purposes of teaching science are, in primary schools?

are there any broader social purposes?

how do you think the purposes of primary science differ from those of secondary?

[show list]

Is there anything important missing from this list?

Anything that should definitely not be a purpose of primary science?

Expectations of pupil progress

what kinds of progress do you expect your pupils to make in science over the course of a year?

ask if nec:

how does this compare with your expectations in other subject areas?

how can you check?

Finally some general questions:

what is your view of the NC for science in KS1 and 2?

are its objectives for primary science the same as yours?

in your view, is primary science about as good as it could be?

how could it be improved?

Post-amble

thank you for your time

as I said earlier, I will send you a transcript of our conversation as soon as I can.

if you see anything in it that you disagree with, please can you let me know? or if there is anything further you want to discuss or to add

Purposes list - pupils:

- becoming self-critical in relation to their own investigations.
- being able to come up with possible explanations for phenomena.
- being able to devise and carry out a fair test.
- being able to make measurements and use equipment correctly.
- being able to record results and write up investigations systematically.
- being able to sort and classify.
- developing a sceptical approach to assertions and evidence.
- developing a sense of wonder at the strangeness of the natural world.
- developing an enquiring mind.
- gaining knowledge of the natural world.
- looking forward to and enjoying science lessons.
- making connections between science and everyday experience.
- making connections between science and other subjects.
- using scientific vocabulary.
- working co-operatively, negotiating agreed procedures and outcomes.

4.5 Interview 5: Planning 2

What can you tell me about the children?

how many?

age range?

- grouping?
 - by ability?
 - in friendship groups?
- individuals or types that stand out/are significant in planning?
 - in any subjects
 - in science
 - having particular difficulties, or finding it easy?
- any other predicted problems?
- What about the unit or topic as a whole?
 - what is it?
 - how many lessons to be spent on it?
 - structure of topic/shape of each lesson
 - main activities, planned classroom states
 - why this way? (strategy, theories of how children learn?)
 - plans to help those with particular difficulties?
 - plans to stretch those who find it easy?
 - how are you planning to introduce the topic?
 - capturing attention - how do you start?
 - ascertaining children's prior notions/preconceptions?
 - making children aware of problems with their everyday understanding?
 - have they done it before?
 - how many times?
 - how recently?
 - will they do this topic again before SATS?
- About your planning:
 - do you set learning objectives for ...
 - each lesson? (e.g.?)
 - the topic as a whole? (e.g.?)
 - particular children/types/groups of children? (e.g.?)
 - is there any other sort of planned differentiation?
 - for the less able?
 - for the more able?
 - is there any particular terminology that you're going to introduce?
 - or units of measurement?
 - instruments/apparatus/equipment?
 - aspects of scientific procedure or method?
 - so the main things they come away with are going to be ...? (re-cap)
 - will they be doing any sort of investigation or practical work themselves?
 - what is the brief?
 - in which lesson(s)?
 - how long do they have?
 - do they get to present their results to the rest of the class?
 - how open-ended/how much autonomy?
 - which bits do you expect them to find easy? ... hard?
 - is this part of the science curriculum that:
 - you think is especially important/valuable?
 - should be given more/less emphasis?
 - provides special insights into the nature of science?

What sort of messages about the nature of science do you think they will get from doing this topic?

Can we just go through the relevant bits of the National Curriculum so I can note the 'bullet points' that you're addressing in this unit?

(go to substantive content page, e.g. "Materials and their properties"... note items to be covered)

(wait to see whether points from 'Experimental and investigative science' are volunteered... if not, prompt and note items to be covered)

(wait to see whether points from 'Systematic enquiry/Science in everyday life/Nature of scientific ideas/Communication/Health and safety' are volunteered... if not, prompt and note items to be covered)

Does this plan differ from the last time you taught this topic?

Are you aware of any ways in which your approaches to planning have changed since you started teaching? more recently?

Are you aware of any ways in which your approaches to teaching have changed since you started teaching? more recently?

Are you aware of any ways in which your views on the nature of science have changed since we started this project? (e.g. on the relationship between evidence and theory ... on how we know what we think we know, and how sure we can be of it ... on what science gives us knowledge of? - reality? phenomena?)

Do you think there are any parallels between how children learn science, and how scientific knowledge itself is created?

Anton Chekhov said that "Man is what he believes". So in a sense the science you are teaching is helping to create the children's beliefs about the world, which in some way shape the people that they become ... what kinds of shaping effects would you like your science teaching to have?

Another quote .. "Education is not the filling of a pail, but the lighting of a fire". I think W B Yeats said that. Any comments?

And finally ... how have you found the experience of taking part in this project? given the perhaps unusually taxing nature of the interviews and the kinds of question we've been looking at? on balance, are you glad you decided to take part? .. or do you wish you hadn't? .. why?

5. Survey

5.1 Questionnaire

The covering letter sent out with the questionnaire was as follows:

Dear E833 Student,

I appreciate that you have been written to recently by the Open University, as part of the Annual Courses Survey: but please can I ask for your patience and co-operation in completing one more questionnaire?

This questionnaire is not connected with the O.U. courses survey. It is part of a research project being carried out at the O.U.'s Centre for Science Education. The project is investigating teachers' thinking about the nature of science and their views on the place and purpose of science teaching in primary practice. We are asking everyone on the 1998 presentation of E833 to fill it in.

As far as possible it is a 'tick the box' sort of questionnaire, but some questions are more open, and you are encouraged to add extra comments anywhere if the options offered do not seem appropriate. It is divided into sections covering your present position; your own school days; yourself outside school; your views on the nature of science; and your views on primary science teaching. It should not take more than 20-25 minutes to do altogether.

Please try to respond to each question, and please bear in mind that this is an attempt to find out how you see things, not a test of what you know.

All personal data will be treated in strictest confidence, and any published results will be completely anonymous and unattributable - in fact the researchers will have no idea who has filled in what. That being the case, if you would like a copy of any reports that come out of the project, please enclose a note of your name and address with your completed form, and we will make sure you go on the mailing list.

We enclose a pre-paid sticky label for you to mail the form back to the O.U. - it would be useful if you could try to get it on its way back to us *within seven days of your receiving it*.

Thank you and best wishes,

Yours,

Stephen Lunn

Centre for Science Education, Open University

p.s. if you have any queries about the questionnaire, or would like to discuss the project that it forms part of, please do not hesitate to contact me (phone 01908 654616 or email s.a.lunn@open.ac.uk).

The following four pages show the questionnaire as sent out respondents.

Primary teachers' thinking about science: survey form

1. About your present position

- 1.1 Are you a class teacher? Yes ☐ No ☐ if not, what do you do? _____
- 1.2 How many hours per week do you teach your class science? _____
- 1.3 Does anyone else teach your class science? Yes ☐ No ☐
- 1.4 Are you a subject co-ordinator? Yes ☐ No ☐ if so which subject(s)? _____
- 1.5 How many children in your present class? _____ What age range? _____
- 1.6 Please indicate: your age: _____ your gender: M ☐ F ☐ the year you qualified: _____
the total number of years you have been teaching: _____

2. About your own school days

- 2.1 Can you remember doing any science at primary school: if so what kind of thing?
No science at all----- ☐
Some nature study ----- ☐
Some physical science-- ☐
Other (please describe) - ☐ _____

2.2 At secondary school:

What science subjects did you study to GCSE/O level?

General Science ☐ Biology ☐ Chemistry ☐ Physics ☐ Other ☐ _____

How did you feel about sciences at the time?

(circle 1 if you strongly disagree, 2 disagree, 3 not sure, 4 agree, 5 strongly agree)

- | | | | | | |
|---|---|---|---|---|---|
| Science was daunting----- | 1 | 2 | 3 | 4 | 5 |
| Science was interesting----- | 1 | 2 | 3 | 4 | 5 |
| I was confident I could do it----- | 1 | 2 | 3 | 4 | 5 |
| Science was not a subject for girls----- | 1 | 2 | 3 | 4 | 5 |
| It wasn't cool to be good at science----- | 1 | 2 | 3 | 4 | 5 |
| Other (please describe) _____ | 1 | 2 | 3 | 4 | 5 |

What GCE 'A' levels did you take? _____

- 2.3 Were there teachers who inspired a lasting interest in their subject? Yes ☐ No ☐
- 2.4 Were there teachers who inspired a lasting interest in teaching? Yes ☐ No ☐
- 2.5 How did you qualify for teaching? Subjects/Specialisations
First degree: B.A. ☐ B.Sc. ☐ B.Ed. ☐ _____
Post-graduate: PGCE ☐ Other ☐ _____
School-based scheme ☐ _____

3. About yourself outside school

- 3.1 Do you see yourself as someone who is interested in science outside school? 1 2 3 4 5
(circle 1 if you actively avoid science, 2 not interested, 3 not sure, 4 interested, 5 very interested)
- 3.2 Do you follow any science in the media?
on t.v. or radio----- ☐
in popular science books or specialist magazines----- ☐
in newspapers ----- ☐
in museums, lectures, events ----- ☐
- 3.3 How do you feel about environmental groups like Greenpeace and Friends of the Earth?
Anti ----- ☐
Indifferent ----- ☐
Sympathetic----- ☐
Member ----- ☐
Activist ----- ☐

4. About your views on the nature of science

(In this section, please circle 1 for strongly disagree, 2 disagree, 3 not sure, 4 agree, 5 strongly agree. Please bear in mind that the questions refer to *science in general, not just to science education.*)

4.1 Scientific knowledge:

- is always tentative, never certain. ----- 1 2 3 4 5
is special because it is factual, not just belief or opinion. ----- 1 2 3 4 5
is no more likely to be true than common sense. ----- 1 2 3 4 5
varies: some parts are more likely to be true than others. ----- 1 2 3 4 5
is not special, it is only one of many ways of knowing about the world. ----- 1 2 3 4 5

4.2 What is science?

- Science is the only way of finding out about the reality that lies behind the world of appearances. ----- 1 2 3 4 5
Science is one of several ways of finding out about the reality that lies behind the world of appearances. ----- 1 2 3 4 5
Science is only about observables, and tells us nothing about any underlying reality. --- 1 2 3 4 5
The world of appearances *is* reality: science gives us an ordered account of it. ----- 1 2 3 4 5
What matters about scientific knowledge is whether it is useful to us in understanding our experience of the world - rather than whether it is 'true' or 'coherent' or how it relates to 'reality'. ----- 1 2 3 4 5

4.3 Scientific knowledge:

- can always be verified by experiment and observation. ----- 1 2 3 4 5
might at any time be falsified by experiment and observation. ----- 1 2 3 4 5
is often little more than common sense wrapped up in inaccessible language. ----- 1 2 3 4 5
is a consensus negotiated between scientists interested in a particular area. ----- 1 2 3 4 5
is created by scientists' theoretical interpretations of experiments and observations. ----- 1 2 3 4 5

4.4 Some would argue that 'acts of faith' underpin scientific beliefs. Which of the following do you think are necessary (if any)?

- Faith in the ability and integrity of scientists and the scientific community. ----- 1 2 3 4 5
Faith that valid scientific explanations are possible, even when we don't have them. --- 1 2 3 4 5
Faith that there are no mysteries that could not ultimately yield to scientific enquiry. ----- 1 2 3 4 5
Faith that applying the scientific method will eventually lead us to the truth. ----- 1 2 3 4 5
Faith that the universe is orderly and consistent. ----- 1 2 3 4 5
Faith that all science will one day be useful to mankind, however irrelevant it might seem now. ----- 1 2 3 4 5

4.5 When they conduct an experiment, do you think scientists usually:

- have no idea what will happen? ----- 1 2 3 4 5
have a good idea what will happen? ----- 1 2 3 4 5
think they know exactly what will happen? ----- 1 2 3 4 5
keep an open mind about what will happen? ----- 1 2 3 4 5

4.6 Scientific theories:

- are well-established explanations of natural phenomena. ----- 1 2 3 4 5
are guesses or hypotheses. ----- 1 2 3 4 5
come from experimental data. ----- 1 2 3 4 5
come from the imagination of scientists. ----- 1 2 3 4 5
have been explored and understood, but are not yet proven. ----- 1 2 3 4 5
are sufficiently well-established to serve as foundations for technological developments. 1 2 3 4 5

- 4.7 Progress in science:
- | | | | | | |
|--|---|---|---|---|---|
| comes from the steady accumulation of facts about the world. | 1 | 2 | 3 | 4 | 5 |
| comes from the development of increasingly powerful explanations of the world. | 1 | 2 | 3 | 4 | 5 |
| depends on the sudden appearance of new ways of looking at the world. | 1 | 2 | 3 | 4 | 5 |
| is really the development of new ways of talking about the world. | 1 | 2 | 3 | 4 | 5 |
| is an illusion: new explanations are not necessarily better than old, they're just different | 1 | 2 | 3 | 4 | 5 |

5. About yourself and science teaching

5.1 If there was no National Curriculum, and you had a completely free hand, what would you do about your science teaching?

- No change from Curriculum ☐
- Reduce science content -----☐ e.g. by removing _____
- Increase science content -----☐ e.g. by adding _____
- Change balance of activities--☐ e.g. by _____

5.2 Do you ever discuss topical issues with a scientific aspect (e.g. solar eclipse, BSE, global warming) with your class?

- No ☐ because: ☐ no time ☐ can be too sensitive
- ☐ against school policy ☐ not interested
- ☐ other reason _____
- Yes ☐ most recent issue discussed _____

5.3 "If you don't know it, you can't teach it". Do you agree? Yes ☐ No ☐

Please give your reasons:

5.4 What do you do when you're unsure how to answer a child's question?
(circle 1 for not at all likely, 2 unlikely, 3 not sure, 4 likely, 5 very likely)

- | | | | | | |
|--|---|---|---|---|---|
| say 'I'll find out and we'll deal with it later' | 1 | 2 | 3 | 4 | 5 |
| say 'You can find out for homework' | 1 | 2 | 3 | 4 | 5 |
| discuss what kinds of answer it might have, what kinds of evidence might help decide | 1 | 2 | 3 | 4 | 5 |
| offer a plausible guess and keep your fingers crossed..... | 1 | 2 | 3 | 4 | 5 |
| discuss how some kind of reference source could be used to find the answer | 1 | 2 | 3 | 4 | 5 |
| something else: _____ | 1 | 2 | 3 | 4 | 5 |

5.5 Would you like to work on and improve aspects of your science teaching? Yes ☐ No ☐

such as? _____

5.6 How important do you think the following are, as goals or purposes of primary science education: (circle 1 for not at all important, 5 for very important)

- | | | | | | |
|--|---|---|---|---|---|
| Pupils becoming self-critical in relation to their own investigations. | 1 | 2 | 3 | 4 | 5 |
| Pupils being able to come up with possible explanations for phenomena..... | 1 | 2 | 3 | 4 | 5 |
| Pupils being able to devise and carry out a fair test..... | 1 | 2 | 3 | 4 | 5 |
| Pupils being able to make measurements and use equipment correctly..... | 1 | 2 | 3 | 4 | 5 |
| Pupils being able to record results and write up investigations systematically. | 1 | 2 | 3 | 4 | 5 |
| Pupils being able to sort and classify..... | 1 | 2 | 3 | 4 | 5 |
| Pupils developing a sceptical approach to assertions and evidence. | 1 | 2 | 3 | 4 | 5 |
| Pupils developing a sense of wonder at the strangeness of the natural world. | 1 | 2 | 3 | 4 | 5 |
| Pupils developing an enquiring mind..... | 1 | 2 | 3 | 4 | 5 |

Pupils gaining knowledge of the natural world. -----	1	2	3	4	5
Pupils looking forward to and enjoying science lessons. -----	1	2	3	4	5
Pupils making connections between science and everyday experience. -----	1	2	3	4	5
Pupils making connections between science and other subjects. -----	1	2	3	4	5
Pupils using scientific vocabulary. -----	1	2	3	4	5
Pupils working co-operatively, negotiating agreed procedures and outcomes. -----	1	2	3	4	5

5.7

How comfortable you feel about teaching the following subjects:
(circle 1 for least comfortable, 5 for most comfortable)

Art-----	1	2	3	4	5
Design & Technology -----	1	2	3	4	5
English -----	1	2	3	4	5
Geography -----	1	2	3	4	5
History -----	1	2	3	4	5
Information Technology -----	1	2	3	4	5
Maths -----	1	2	3	4	5
Music -----	1	2	3	4	5
P.E. -----	1	2	3	4	5
Science -----	1	2	3	4	5

5.8

What are your main concerns when preparing to teach a science topic?
(circle 1 for no concern at all, 5 for a frequent and major concern)

Being able to explain the concepts at the children’s level. -----	1	2	3	4	5
Whether your planned activity is really science. -----	1	2	3	4	5
Lack of or inappropriate resources.-----	1	2	3	4	5
That you do not know enough of the relevant science.-----	1	2	3	4	5
That you do not know whether you know enough of the relevant science.-----	1	2	3	4	5
How to make a boring topic interesting to the children.-----	1	2	3	4	5
How to organise and manage behaviour in practical work.-----	1	2	3	4	5
Something else:-----	1	2	3	4	5

5.9

Is there anything else you would like to say about yourself, children, science, learning or teaching?

Thank you for taking the time and trouble to complete this questionnaire.

Now please return it to the O.U. using the pre-paid sticky label provided.

Please do not forget to enclose a note of your own name and address if you would like copies of research reports arising from this survey.

5.2 Notes on Statistics

5.2.1 Background variables

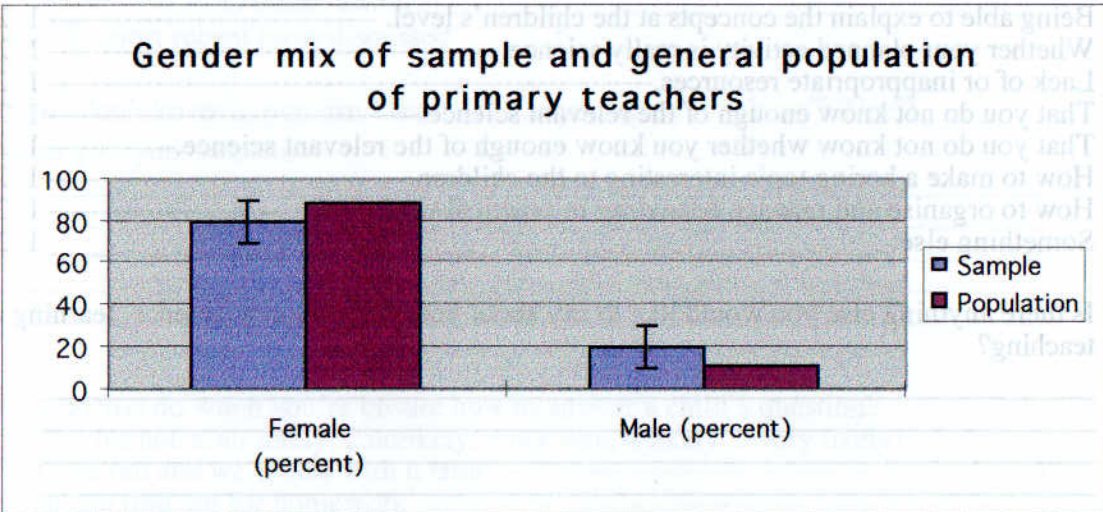
Confidence limits on population estimates

95% confidence intervals on generalisation of a proportion $p\%$ of the sample N to the population of primary teachers, assuming that the sample is representative, are calculated by:

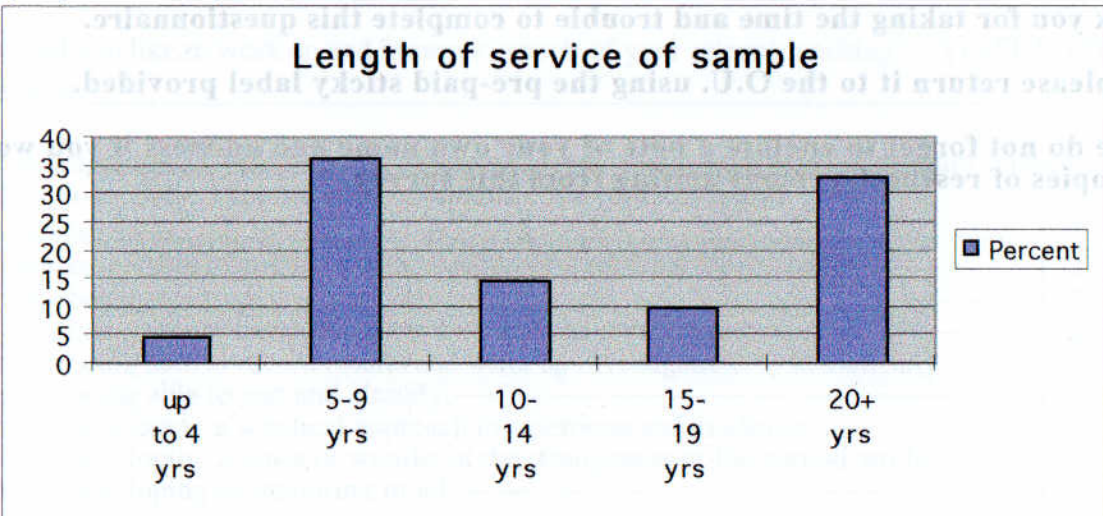
$$\text{population estimate} = p \pm 1.96\sqrt{p(100-p)/N}$$

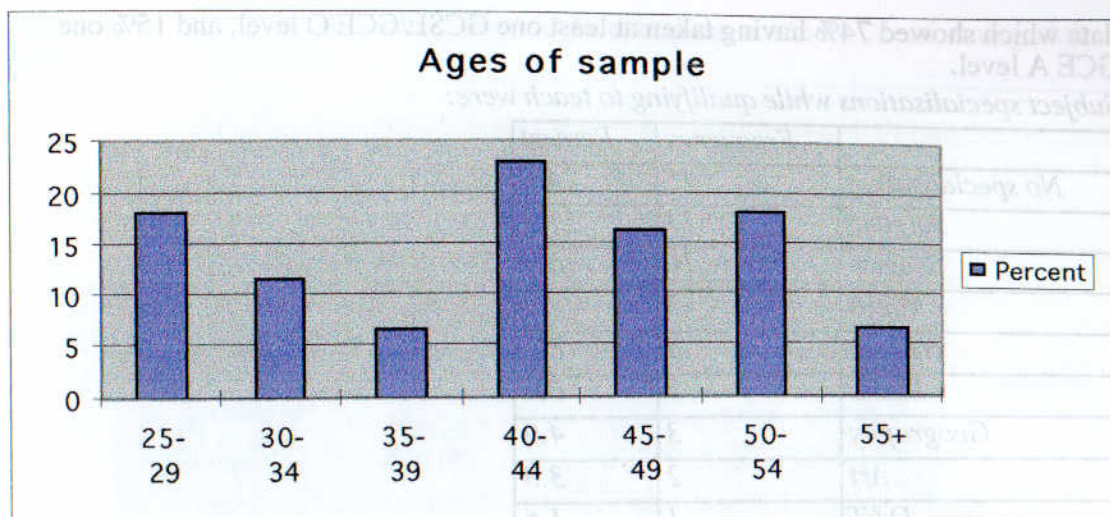
A 95% confidence interval is an interval such that 95% of intervals so constructed contain the population value. 90% intervals would result from substituting 1.65 for 1.96; 99% by substituting 2.55. The formula assumes the population is 'infinitely' large compared to the sample - correcting for this would require multiplying the standard error term $\sqrt{p(100-p)/N}$ by $\sqrt{(1-(\text{sample } N/\text{population } N))} = 0.999996$, a correction sufficiently close to 1 to make no difference.

A tentative indication of the representativeness of the sample (on the assumption of which the statistical significance tests are based) was gained by comparing the gender mix of the sample with that of the general population of primary teachers (DfEE 1999). It will be observed that the population actuals lie within the 95% confidence interval of the sample (error bars on all graphs show 95% confidence intervals unless indicated to the contrary).

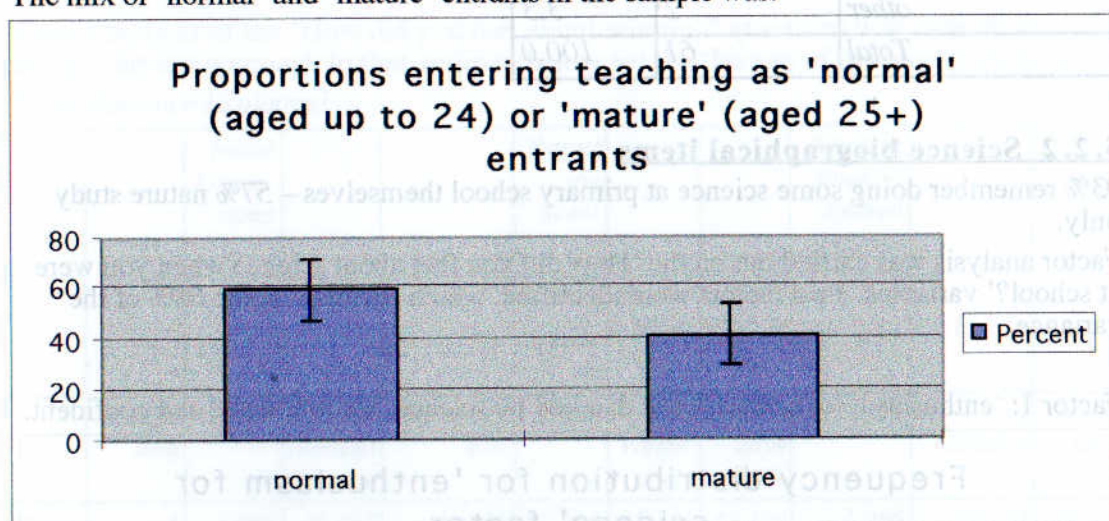


Length of service and age of the sample would not be expected to be similar to that of the general population, since for example few newly qualified teachers would be expected on the OU Masters course. The distributions of length of service and age group in the sample are as follows:





The mix of 'normal' and 'mature' entrants in the sample was:



Thus the sample suggests that females are more likely ($p < 0.1$) than males to come into teaching as mature entrants - this information is not available for the general population.

Females are significantly ($p < 0.1$) more likely than males to come into teaching as mature entrants:

entry/gender crosstab	'normal'	'mature'	Total
female	26	23	49
male	10	2	12
Total	36	25	61

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.652	1	.056
N of Valid Cases	61		

Teachers in the sample spend around two hours per week teaching science to their classes, which are typically of 28 children. Two people teach no science at all: seven do not do all the science teaching for their class. 80% are subject co-ordinators - over half of these for English, science or maths.

92% of the sample took at least one science to GCSE. Biology was taken more often than other subjects. 65% took three or more 'A' levels. 62% took no sciences to 'A' level, thus 38% one or more: 26% one science only, 12% two or more. 31% took biology, 15% chemistry, 8% physics to 'A' level. This compares with de Boo's (1989)

data which showed 74% having taken at least one GCSE/GCE O level, and 15% one GCE A level.

Subject specialisations while qualifying to teach were:

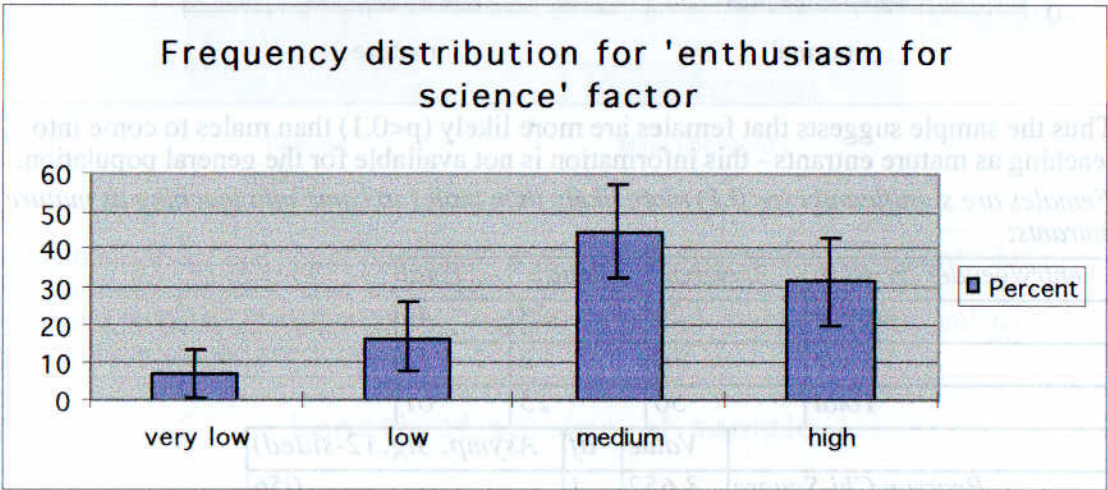
	Frequency	Percent
No specialisation	15	24.6
English	13	21.3
Science	10	16.4
Maths	5	8.2
History	5	8.2
Music	4	6.6
Geography	3	4.9
Art	2	3.3
D&T	1	1.6
Modern Languages	1	1.6
other	2	3.3
Total	61	100.0

5.2.2 Science biographical items

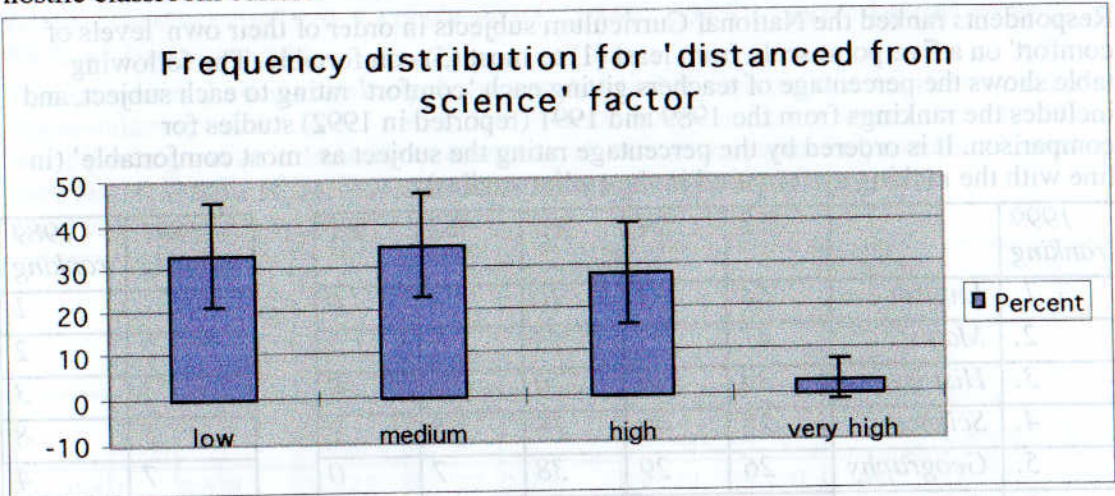
93% remember doing some science at primary school themselves – 57% nature study only.

Factor analysis was carried out on the ‘How did you feel about science when you were at school?’ variables. Two factors were identified, which ‘explain’ some 68% of the variance.

Factor 1: ‘enthusiasm for science’: not daunted by science, but interested and confident.



Factor 2: 'distanced from science': not a subject for girls, not 'cool', conforming with hostile classroom culture.



Factor analysis of the ‘How did you feel about science?’ questions was carried out using a similar approach to that outlined below for the ‘Nature of Science’ questions.

Total Variance Explained

		Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Rescaled	1	2.906	46.483	46.483	2.266	45.316	45.316	1.986	39.714	39.714
	2	1.375	21.998	68.481	1.149	22.974	68.290	1.429	28.576	68.290

Rotated Component Matrix

	Raw Component	Rescaled Component	
	1	2	1
science was daunting	-.1055		-.879
science was interesting	.856		.734
I was confident I could do it	.845		.797
science not a subject for girls		.958	.852
not 'cool' to be good at science		.818	.794

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

Nearly 80% say they take an interest in science outside school. General news media (t.v., radio, newspapers) are the most frequently used means.

Over 80% of respondents were sympathetic to or members of environmental groups like Greenpeace or Friends of the Earth.

5.2.3 Ranking of subjects by how comfortable teachers feel about teaching them

Respondents ranked the National Curriculum subjects in order of their own 'levels of comfort' on a five point scale from least (1) to most (5) comfortable. The following table shows the percentage of teachers giving each 'comfort' rating to each subject, and includes the rankings from the 1989 and 1991 (reported in 1992) studies for comparison. It is ordered by the percentage rating the subject as 'most comfortable' (in line with the ranking system used in the earlier studies).

1999 ranking		%5	%4	%3	%2	%1	1991 ranking	1989 ranking
1.	English	54	33	10	3	0	1	1
2.	Maths	47	33	13	5	2	2	2
3.	History	39	34	20	7	0	5	3
4.	Science	28	49	16	5	2	3	8
5.	Geography	26	29	38	7	0	7	4
6.	Art	25	29	18	18	10	4	5
7.	ICT	21	31	15	12	21	n/a	n/a
8.	PE	18	26	23	20	13	6	6
9.	D&T	16	31	25	20	8	10	10
10.	Music	13	13	20	26	28	9	9

Mean 'comfort levels' and standard deviations are given below: a linear model 'repeated measures' test shows that the differences between subjects are significant at the .001 level, by F-test (df 9, 52; $F_{.001} = 4.21$; $F = 18.497$).

1999 ranking		Mean	Std. Deviation	N
1.	English	4.38	.80	61
2.	Maths	4.20	.96	61
3.	History	4.07	.93	61
4.	Science	3.97	.89	61
5.	Geography	3.75	.92	61
6.	Art	3.41	1.31	61
7.	D&T	3.28	1.20	61
8.	ICT	3.20	1.46	61
9.	PE	3.16	1.31	61
10.	Music	2.57	1.37	61

Similar results arise when comfort levels are adjusted to remove the effect of different individual response biases, by recalculating the comfort level for each subject for each respondent as (comfort level allocated to that subject by that respondent - mean comfort level across all subjects for respondent).

5.2.4 Factor analysis for 'Nature of Science' questions

The data consist of 'level of agreement' responses in the range 1 (strongly disagree) through 3 (not sure) to 5 (strongly agree), to thirty-six individual statements relating to six broad areas of interest, as described above. To paraphrase Kline (1994, p10), the data are complex, and it is uncertain what the most important variables in the field are: so exploratory factor analysis was applied to the six areas of interest, in an attempt to identify variables that might contribute usefully to explaining differences in responses at the same time as compressing the data.

Principal components analysis was used with various combinations of method: correlation and co-variance matrices; extraction of Eigen-values greater than 1.0 to 1.3 times the mean; unrotated and Varimax rotation; various ways of dealing with missing values (stepwise, pairwise, substitution with mean, and default); and elimination of

variables loading approximately evenly across several factors. **Six factors emerged as stable across the range of methods, and as significant (for N=61) with factor loadings of > 0.7 (Hair et al., 1995, p385), 'explaining' over 80% of the variance.**

The extraction shown is a principal components analysis by co-variance matrix, with Eigen-values greater than the mean, and Varimax rotation. Factor scores were stored using the 'regression' method for estimating co-efficients, producing a mean of zero for each factor. Details of the factors extractions are given below.

Total Variance Explained

		Initial Eigen- values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Comp onent	Total	% of Variance	Cumulat ive %	Total	% of Variance	Cumulat ive %	Total	% of Variance	Cumulat ive %
Rescaled	1	2.538	21.122	21.122	2.306	19.220	19.220	2.194	18.287	18.287
	2	2.181	18.152	39.275	2.090	17.420	36.640	1.810	15.081	33.368
	3	1.679	13.971	53.246	1.740	14.498	51.138	1.639	13.661	47.029
	4	1.306	10.871	64.116	1.277	10.639	61.777	1.520	12.669	59.698
	5	1.134	9.435	73.551	1.171	9.758	71.535	1.259	10.496	70.193
	6	1.017	8.461	82.012	1.035	8.627	80.162	1.196	9.969	80.162

Rotated Component Matrix

	Raw						Rescaled					
	Component						Component					
	1	2	3	4	5	6	1	2	3	4	5	6
sci kn no more true than common sense						1.038						.967
only way of finding out about reality behind appearances	.788						.794					
usefulness is all that matters - forget truth, coherence, reality					1.190						.978	
no mysteries that won't ultimately yield	.919						.842					
sci method will eventually lead to truth	.945						.870					
keep an open mind		.849						.903				
guesses or hypotheses				.865						.854		
come from the imagination				.847						.807		
steady accumulation of facts		.453						.588				
sudden appearance of new ways of looking		.651						.736				
new ways of talking			.813						.870			
progress illusory: new not better, just differen			.723						.824			

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

The following notes characterise the factors extracted, by way of a short-hand 'tag', a summary of associated positions, and a table showing the most significant factor loadings from the rescaled rotated component matrix.

Factor 1: 'scientism'. The position that scientific method will lead to the truth, that there are no mysteries that will not eventually yield, that science is the only way of finding out about the reality behind phenomena.

<i>sci method will eventually lead to truth</i>	<i>.870</i>
<i>no mysteries that won't ultimately yield</i>	<i>.842</i>
<i>only way of finding out about reality behind appearances</i>	<i>.794</i>

Factor 2: 'naive empiricism'. The position that science proceeds by trying things out to 'see what happens', and is driven by data derived from such observations.

<i>scientists keep an open mind</i>	<i>.903</i>
<i>sudden appearance of new ways of looking</i>	<i>.736</i>
<i>steady accumulation of facts</i>	<i>.588</i>

Factor 3: 'new-age-ism'. The position that progress in science consists of new ways of talking which are not intrinsically better than older ways, just different.

<i>new ways of talking</i>	<i>.870</i>
<i>progress illusory: new not better, just different</i>	<i>.824</i>

Factor 4: 'constructivism'. The position that science is rooted in attempts to construct explanations which originate in speculation and the human imagination.

<i>guesses or hypotheses</i>	<i>.854</i>
<i>come from the imagination</i>	<i>.807</i>

Factor 5: 'pragmatism'. The position that truth, coherence, and correspondence with reality are immaterial, and that what matters is the usefulness of science in helping us understand our experience.

<i>usefulness is all that matters - forget truth, coherence, reality</i>	<i>.978</i>
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Factor 6: 'scepticism'. The position that science has no claims to specialness, and is no more likely to be true than 'common sense'.

<i>sci kn no more true than common sense</i>	<i>.967</i>
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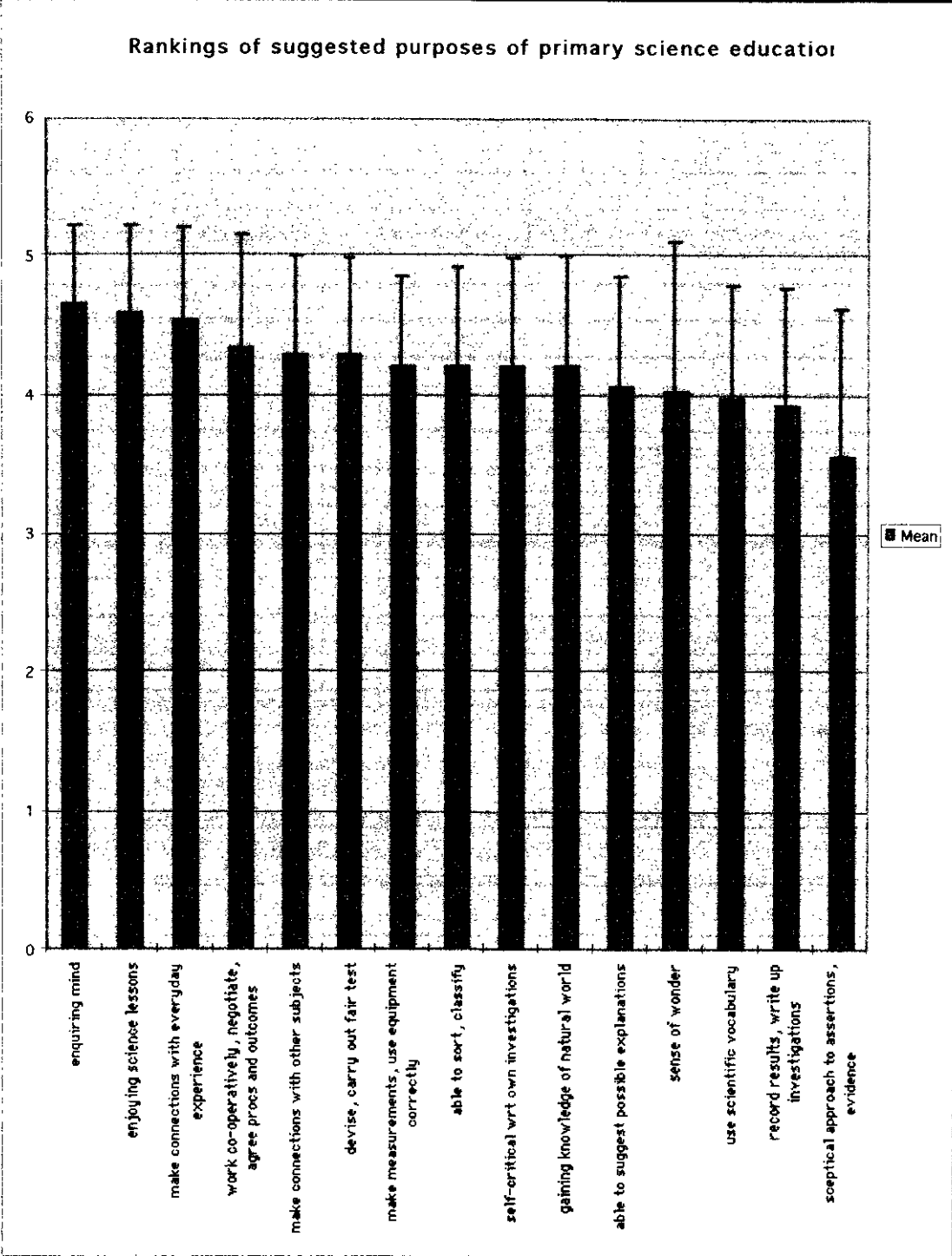
5.2.5 The purposes of primary science education

Mean rankings of importance of the fifteen suggested purposes of primary science education, and standard deviations, are given below: a linear model 'repeated measures' test shows that the differences between purposes are significant at the .001 level, by F-test (df 14, 47; $F_{.001} [10, 40] = 3.87$; $F = 7.48$). Error bars on the graph represent standard deviation.

Developing an enquiring mind, enjoying science lessons, and making connections between science and children's everyday experience, came out as the most favoured purposes: developing a sceptical approach to assertions and evidence the least.

	<i>Mean</i>	<i>Std. Deviation</i>
<i>enquiring mind</i>	<i>4.67</i>	<i>.57</i>
<i>enjoying science lessons</i>	<i>4.59</i>	<i>.64</i>
<i>make connections with everyday experience</i>	<i>4.54</i>	<i>.67</i>
<i>work co-operatively, negotiate, agree procs and outcomes</i>	<i>4.34</i>	<i>.83</i>
<i>make connections with other subjects</i>	<i>4.30</i>	<i>.72</i>
<i>devise, carry out fair test</i>	<i>4.28</i>	<i>.71</i>
<i>make measurements, use equipment correctly</i>	<i>4.21</i>	<i>.66</i>
<i>able to sort, classify</i>	<i>4.21</i>	<i>.73</i>
<i>self-critical with respect to own investigations</i>	<i>4.20</i>	<i>.79</i>

<i>gaining knowledge of natural world</i>	4.20	.81
<i>able to suggest possible explanations</i>	4.05	.80
<i>sense of wonder</i>	4.02	1.09
<i>use scientific vocabulary</i>	3.97	.82
<i>record results, write up investigations</i>	3.93	.85
<i>sceptical approach to assertions, evidence</i>	3.56	1.06



Similar results arise when purpose ratings are adjusted to remove the effect of different individual response biases, by recalculating the rating for each purpose for each respondent as (rating allocated to that purpose by that respondent - mean rating across all purposes for that respondent).

Factor analysis of the ‘Purposes of primary science’ variables was carried out using a similar approach to that outlined above for the ‘Nature of Science’ questions.

Total Variance Explained

		Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Rescaled	1	2.273	46.486	46.486	3.643	45.543	45.543	2.932	36.656	36.656
	2	.977	19.985	66.470	1.563	19.541	65.083	2.146	26.821	63.477
	3	.673	13.771	80.241	.945	11.811	76.894	1.073	13.417	76.894

Rotated Component Matrix

	Raw Component			Rescaled Component		
	1	2	3	1	2	3
devise, carry out fair test	.519			.731		
make measurements, use equipment correctly	.538			.813		
record results, write up investigations	.779			.913		
sense of wonder		1.030			.947	
gaining knowledge of natural world	.598			.735		
enjoying science lessons	.529			.824		
make connections with everyday experience	.587			.873		
make connections with other subjects	.600			.839		

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

5.2.6 The role of subject knowledge in primary science teaching

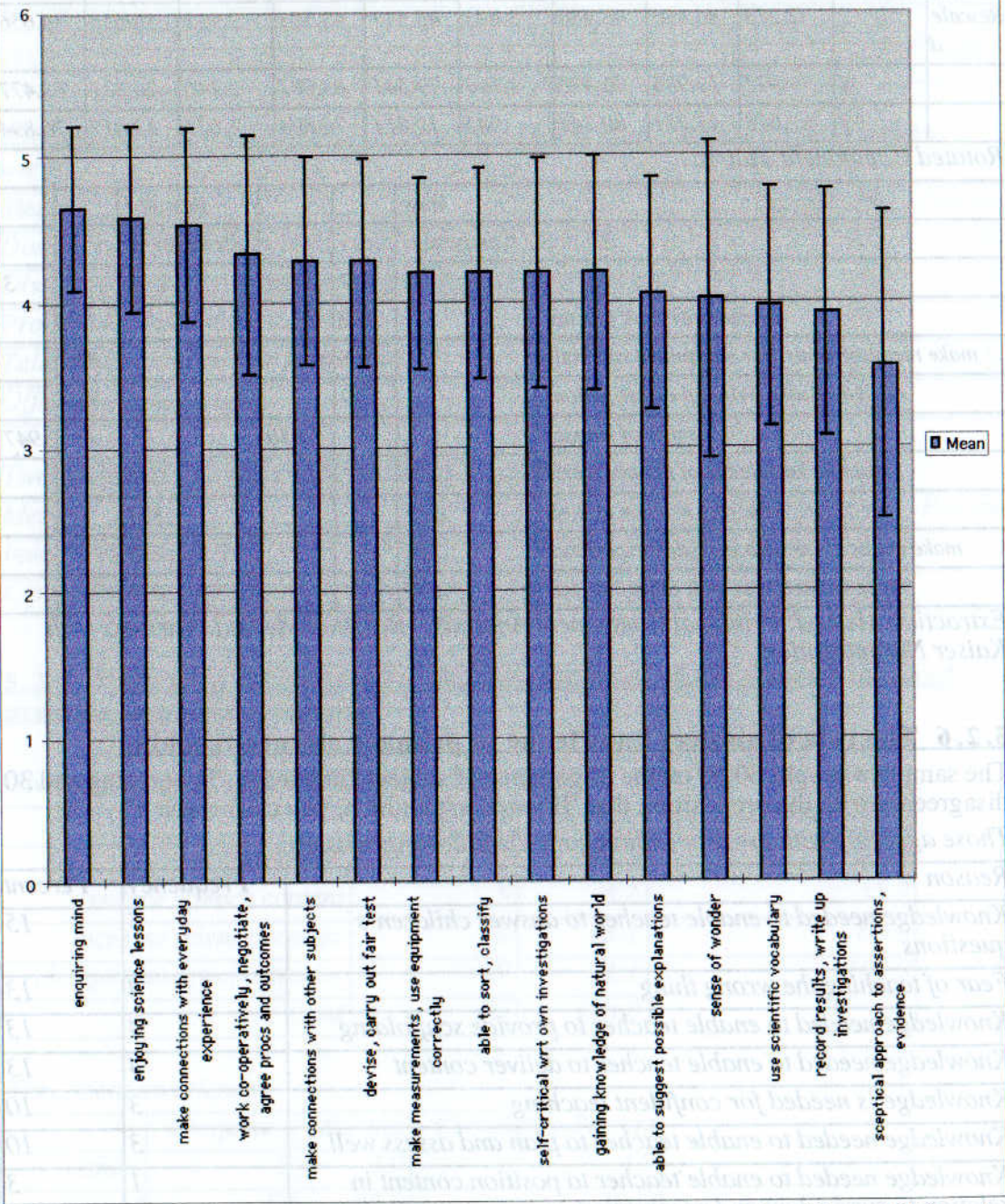
The sample was split 50:50 on the importance of subject knowledge, 31 agreeing and 30 disagreeing with the proposition that 'If you don't know it, you can't teach it'.

Those agreeing with the proposition gave the following reasons:

Reason	Frequency	Percent
Knowledge needed to enable teacher to answer children's questions	5	15
Fear of teaching the wrong thing	4	13
Knowledge needed to enable teacher to provide scaffolding	4	13
Knowledge needed to enable teacher to deliver content	4	13
Knowledge is needed for confident teaching	3	10
Knowledge needed to enable teacher to plan and assess well	3	10
Knowledge needed to enable teacher to position content in relation to curriculum and progression	1	3
Knowledge needed to enable teacher to make content interesting	1	3
No reason given	6	20
Total	31	100.0

<i>gaining knowledge of natural world</i>	4.20	.81
<i>able to suggest possible explanations</i>	4.05	.80
<i>sense of wonder</i>	4.02	1.09
<i>use scientific vocabulary</i>	3.97	.82
<i>record results, write up investigations</i>	3.93	.85
<i>sceptical approach to assertions, evidence</i>	3.56	1.06

Rankings of suggested purposes of primary science education



Similar results arise when purpose ratings are adjusted to remove the effect of different individual response biases, by recalculating the rating for each purpose for each respondent as (rating allocated to that purpose by that respondent - mean rating across all purposes for that respondent).

Factor analysis of the 'Purposes of primary science' variables was carried out using a similar approach to that outlined above for the 'Nature of Science' questions.

Science practical

	<i>Frequency</i>	<i>Percent</i>	<i>Cumulative Percent</i>
<i>unchanged</i>	44	72.1	72.1
<i>increase</i>	17	27.9	100.0
<i>Total</i>	61	100.0	

Making connections

	<i>Frequency</i>	<i>Percent</i>	<i>Cumulative Percent</i>
<i>unchanged</i>	47	77.0	77.0
<i>increase</i>	14	23.0	100.0
<i>Total</i>	61	100.0	

More fun, topical, interesting

	<i>Frequency</i>	<i>Percent</i>	<i>Cumulative Percent</i>
<i>unchanged</i>	41	67.2	67.2
<i>increase</i>	20	32.8	100.0
<i>Total</i>	61	100.0	

5.2.8 Extra-curricular science

Forty-three (over 70%) of the sample bring extra-curricular science into their classrooms.

Of the 18 (30%) who do not, their reasons are:

<i>Reason</i>	<i>Frequency</i>	<i>Percent</i>
<i>no time</i>	11	61
<i>children too young</i>	4	22
<i>other</i>	3	17

5.2.9 Professional development: how would they improve their own science teaching?

79% (48) of the sample felt that they could improve their science teaching

These cited the following means:

<i>How to improve</i>	<i>Frequency</i>	<i>Percent of those wanting to improve citing this reason</i>
<i>Working on ATL (see below for breakdown)</i>	31	65
<i>Improving science content knowledge (see below for breakdown)</i>	16	33
<i>Inset on science for very young or lower ability children</i>	2	4
<i>Collegial sharing/mentoring</i>	2	4
<i>Inset on engaging children in science</i>	1	2
<i>Unspecified</i>	4	8

Breakdown of 'Working on AT1'

31 individuals thought they could improve their science teaching through improving their practical/investigative/AT1 work, 5 wanting 'across the board' improvement. 26 cited specific areas for improvement (some more than one):

Area to be improved	Number citing
Teaching content through practical work	11
Assessment and progression	5
Teaching the thinking skills associated with AT1	5
Developing and managing resources	3
More hands-on experience of doing science to boost the teachers' confidence	3
Using technology/IT/sensors in practical work	2
Classroom management for AT1	2

Breakdown of 'Improving science content knowledge'

16 individuals thought they could improve their science teaching by improving their science content knowledge: 9 wanting 'across the board' improvement, and 7 citing specific areas – 6 citing physics, 2 chemistry and 2 biology.

5.2.10 Concerns

Mean rankings of importance of the seven suggested 'main concerns' when preparing to teach a science topic are given below: a linear model 'repeated measures' test shows that the differences between concerns are significant at the .001 level, by F-test (df 6, 55; $F_{.001}[6, 40] = 4.73$; $F = 8.04$; error bars on chart show standard deviation).

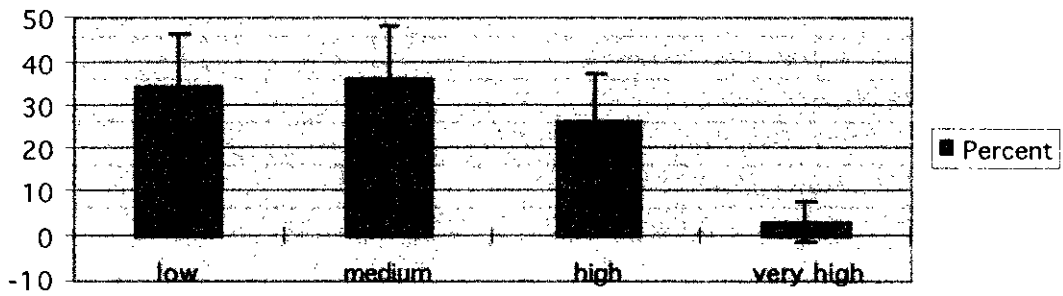
	Mean	Std. Deviation
resources - lack of, or inappropriate	3.34	1.36
explain concepts at children's level	3.33	1.40
make boring topic interesting	2.82	1.38
don't know enough relevant science	2.59	1.26
don't know whether know enough relevant science	2.56	1.34
organise/manage behaviour in practical work	2.39	1.36
is planned activity really science?	2.34	1.25

Similar results arise when concern ratings are adjusted to remove the effect of different individual response biases, by recalculating the rating for each concern for each respondent as (rating allocated to that concern by that respondent - mean rating across all concerns for that respondent).

Factor analysis of the 'Concerns' variables was carried out using a similar approach to that outlined above for the 'Nature of Science' questions. Three factors were identified, 'explaining' some 81% of the variance.

Factor 1: 'subject knowledge': concerned about own subject knowledge and meta-knowledge (e.g. concerned that they do not know enough relevant science; and concerned that they do not know whether they know enough relevant science)..

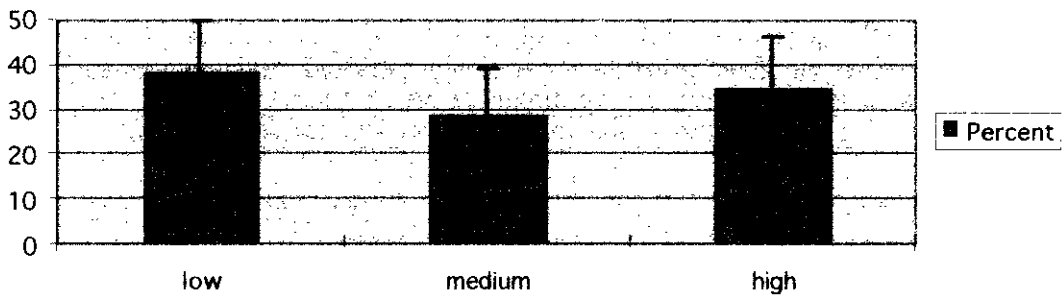
Frequency distribution for 'subject knowledge' factor



This factor is approximately normally distributed, with a few outliers with high levels of concern.

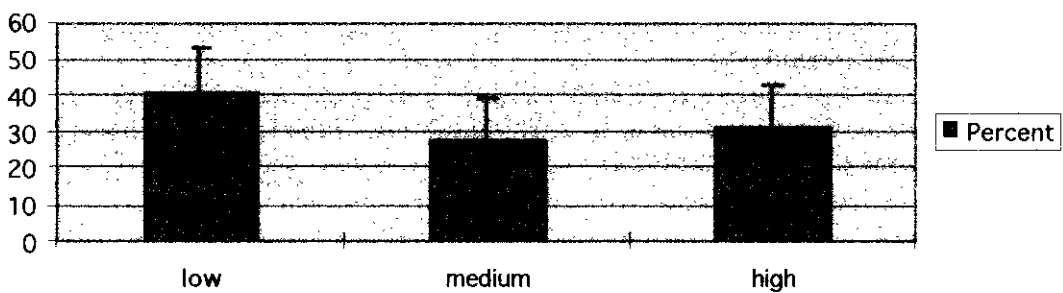
Factor 2: 'communication': concerned about communicating with and engaging children - making it interesting, explaining concepts at the child's level.

Frequency distribution for 'communication' factor



Factor 3: 'organising practicals': concerned about classroom management and organisation in practical work.

Frequency distribution for 'organising practicals' factor



Total Variance Explained

		Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Rescaled	1	4.751	44.642	44.642	2.752	45.866	45.866	2.126	35.425	35.425
	2	2.001	18.803	63.445	1.093	18.221	64.087	1.622	27.027	62.453
	3	1.831	17.200	80.645	.995	16.587	80.674	1.093	18.221	80.674

Rotated Component Matrix

	Raw			Rescaled		
	Component			Component		
	1	2	3	1	2	3
explain concepts at children's level		1.209			.864	
is planned activity really science?						
don't know enough relevant science	1.164			.926		
don't know whether know enough relevant science	1.277			.956		
make boring topic interesting		1.067			.771	
organise/manage behaviour in practical work			1.331			.981

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

5.2.11 Relationships

5.2.11.1 Level of comfort with science teaching

Level of comfort with science teaching is correlated with the following variables:

	Pearson correlation coefficient	p
support for environmental groups	.537	.000
interested in science outside school	.464	.000
following science in media – t.v./radio	.450	.000
GCSE in chemistry	.304	.017
purpose – ‘making connections’	.297	.020
number of science GCSEs	.288	.024
memories of enthusiasm for science at school	.273	.035
unable to answer question – find out for homework	-.378	.003
concern with subject knowledge	-.382	.002

A ‘multiple regression’ linear model linking level of comfort with science teaching, with the most significant three variables, following science in the media - tv/radio, feelings about environmental groups, interested in science outside school, gives the following results for ANOVA:

	<i>Sum of Squares</i>	<i>df</i>	<i>Mean Square</i>	<i>F</i>	<i>Sig.</i>
<i>Regression</i>	20.574	3	6.858	13.208	.000
<i>Residual</i>	29.596	57	.519		
<i>Total</i>	50.171	60			

5.2.11.2 Nature of science

The ‘naive empiricism’ factor, implying that science proceeds by trying things out to ‘see what happens’, and is driven by data derived from such observations, correlates with a focus on method and results as a purpose of primary science, and with length of service:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>purpose – ‘methodism’</i>	.382	.002
<i>length of service as a teacher</i>	.337	.008
<i>age group</i>	.258	.045

‘New-age-ism’ - progress in science consists of new ways of talking which are not intrinsically better than older ways, just different – correlates significantly with level of comfort with music teaching, and less significantly and negatively with a preparedness to find out about issues raised in class, and with number of science A levels.

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>level of comfort with music teaching</i>	.364	.004
<i>unable to answer question – I’ll find out</i>	-.253	.049
<i>number of science ‘A’ levels</i>	-.254	.048

‘Pragmatism’ – philosophical considerations are unimportant, what matters is the usefulness of science in helping us understand our experience – correlates significantly with seeing the development of a sense of wonder as a purpose of science teaching, and with entering teaching as a mature person:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>purpose - wonder</i>	.332	.009
<i>mature entrant to teaching</i>	.381	.002
<i>unable to answer question – discuss reference sources</i>	.283	.027

There are only weak correlations with the ‘scientism’, ‘constructivism’, and ‘scepticism’ factors:

Scientism:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>number of science ‘A’ levels</i>	.272	.034
<i>number of ‘A’ levels</i>	-.270	.035

Constructivism:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>unable to answer question – offer a plausible guess</i>	.285	.026
<i>teacher-inspired lasting interest in teaching</i>	-.254	.048
<i>GCSE in general science</i>	-.260	.043

Scepticism:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>change curriculum by increasing connection between science and children's lives</i>	-.255	.048
<i>following science in media – t.v./radio</i>	-.274	.032
<i>memories of enthusiasm for science at school</i>	-.284	.028

5.2.11.3 Purposes

The purpose tagged 'methodism', emphasising recording, measuring, fair testing, correlates significantly with comfort with geography teaching, surprisingly; with a preference for finding things out for the children; and with a 'naïve empiricist' view of the nature of science:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>level of comfort with geography teaching</i>	.399	.001
<i>unable to answer question – I'll find out</i>	.391	.002
<i>nature of science – 'naïve empiricism'</i>	.382	.002
<i>concern – subject knowledge</i>	.317	.013
<i>number of science GCSEs</i>	-.261	.042
<i>GCSE in chemistry</i>	-.286	.025

The purpose of developing a sense of wonder correlates significantly with the two preferred responses to questions that the teacher is unable to answer which emphasise a constructive, in-line response to queries in which the teacher models meta-cognitive processes; and with a 'pragmatist' view of the nature of science:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>unable to answer question – discuss kinds of answer and evidence</i>	.390	.002
<i>unable to answer question – discuss reference sources</i>	.361	.004
<i>nature of science – 'pragmatism'</i>	.332	.009
<i>change curriculum by increasing time spent doing practical work</i>	.303	.018
<i>interested in science outside school</i>	.293	.022
<i>change curriculum by giving children more autonomy</i>	.269	.036
<i>GCSE in physics</i>	.256	.046

The 'making connections' purpose correlates weakly and unsurprisingly:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>interested in science outside school</i>	.321	.012
<i>level of comfort with science teaching</i>	.297	.020
<i>unable to answer question – discuss kinds of answer and evidence</i>	.297	.020
<i>extra-curricular – topical science</i>	.280	.029

5.2.11.4 Support for environmental groups

The question about environmental groups was included after reflecting on references by several pilot study interviewees to 'green' issues. Support for such groups correlates significantly with comfort in science teaching, with a response to difficult questions that models meta-cognitive processes, and with following science in the broadcast media. There are suggestive weak negative correlations with levels of comfort with P.E. and music teaching.

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>level of comfort with science teaching</i>	.537	.000
<i>unable to answer question – discuss kinds of answer and evidence</i>	.399	.001
<i>following science in media – t.v./radio</i>	.382	.002
<i>interested in science outside school</i>	.317	.013
<i>change curriculum by giving children more autonomy</i>	.281	.028
<i>unable to answer question – discuss reference sources</i>	.263	.041
<i>level of comfort with P.E. teaching</i>	-.292	.022
<i>level of comfort with music teaching</i>	-.296	.021

5.2.11.5 Dealing with questions you cannot answer immediately

Two of the possible responses imply that the teacher will model the meta-cognitive processes involved in thinking about the kinds of answer that might be acceptable, and the kinds of evidence one might seek for it, and in thinking about how to find out from other reference sources. They imply a joint teacher-pupil project to solve the problem, and are significantly correlated with each other, with an interest in science outside school, and with the purpose of developing a sense of wonder. The former ('Discuss kinds of answer and evidence') is also significantly correlated with being comfortable with D&T teaching, and with support for environmental groups, and negatively with being comfortable with P.E. teaching.

Discuss kinds of answer and evidence:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>level of comfort with D&T teaching</i>	.433	.000
<i>support for environmental groups</i>	.399	.001
<i>purpose - wonder</i>	.390	.002

<i>interested in science outside school</i>	.383	.002
<i>unable to answer question – discuss reference sources</i>	.358	.005
<i>following science in media – t.v./radio</i>	.300	.019
<i>purpose – ‘making connections’</i>	.297	.020
<i>age group</i>	.260	.043
<i>mature entrant to teaching</i>	.260	.043
<i>level of comfort with Art teaching</i>	.257	.045
<i>level of comfort with P.E. teaching</i>	-.353	.005

Discuss reference sources:

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>interested in science outside school</i>	.362	.004
<i>purpose - wonder</i>	.361	.004
<i>unable to answer question – discuss kinds of answer and evidence</i>	.358	.005
<i>nature of science – ‘pragmatism’</i>	.283	.027
<i>support for environmental groups</i>	.263	.041
<i>following science in media – newspapers</i>	.254	.049

‘Find out for homework’ and ‘I’ll find out for you’ represent opposite ends of the continuum that a joint teacher-pupil project sits at the middle of. The former is significantly negatively correlated with level of comfort with science teaching; the latter is positively correlated with the purpose tagged ‘methodism’, and negatively with comfort in D&T teaching, and with following science in the newspapers.

‘Find out for homework’

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>concern – subject knowledge</i>	.305	.017
<i>level of comfort with P.E. teaching</i>	.257	.046
<i>following science in media – t.v./radio</i>	-.269	.036
<i>level of comfort with science teaching</i>	-.378	.003

‘I’ll find out for you’

	<i>Pearson correlation coefficient</i>	<i>p</i>
<i>purpose – ‘methodism’</i>	.391	.002
<i>GCSE in physics</i>	-.253	.049
<i>nature of science – ‘new-age-ism’</i>	-.253	.049
<i>number of science GCSEs</i>	-.286	.025
<i>level of comfort with D&T teaching</i>	-.360	.004
<i>following science in media – newspapers</i>	-.380	.002